Proceedings of the

International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris

September 9-11, 2008

University of Washington Tacoma
Tacoma, WA, USA

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PROCEEDINGS OF THE INTERNATIONAL RESEARCH WORKSHOP ON THE OCCURRENCE, EFFECTS, AND FATE OF MICROPLASTIC MARINE DEBRIS

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University of Washington Tacoma, Tacoma, WA, USA

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PREFACE

Welcome to the proceedings of the first International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris held September 9-11, 2008 on the University of Washington Tacoma campus in Tacoma, Washington, USA. These proceedings include an overall summary of the workshop sessions, the participant points of agreement, and suggested research initiatives to move the science of understanding the impacts of microplastics on the marine environment forward. This invitation only workshop was a joint effort between the University of Washington Tacoma and the NOAA Marine Debris Program.

The purpose of the workshop was to bring together environmental research scientists from around the world to discuss the impacts of microplastic interactions and ingestion to marine species, the connection with contaminant uptake by organisms, and to outline the potential next steps in microplastic research. The workshop format combined presentations, breakout groups, and participant discussions during two days of meetings. Thirty two individuals participated in the workshop, representing academic, industrial, private, policy and governmental sectors. Fourteen oral presentations included research on such broad-ranging topics as the oceanography of the North Pacific, the ingestion of microplastics by marine invertebrates, and persistent organic pollutants in marine plastic debris. All fourteen presentations are included here, with abstracts and slides as deemed appropriate by the presenters.

Sessions were organized to focus on four main research topics: (1) the occurrence of small plastic debris in the marine environment, (2) the impacts of small plastic debris on the marine environment, (3) the impacts of small plastic debris exposure to persistent organic pollutants, and (4) the effect of oceanic microplastics on biogeochemical cycling of persistent organic pollutants. A review paper, currently in preparation for consideration of publication, was distributed to participants before the workshop to capture the overarching themes of these four sessions, and to ensure all participants were equally familiar with each session topic. One final session included three breakout groups: sources and sinks of plastics in the marine environment, effects of microplastic debris on marine organisms, and the role of microplastics in POP cycling and exposure. The workshop closed with presentations from each breakout group that summarized discussions on the state of the science, key research gaps and potential research initiatives. Following the two day workshop was a half day meeting of the Steering Committee consisting of the participant breakout leads, session rapporteurs, and the workshop organizers to help consolidate the information and draft the final workshop proceedings.

Appendices include the workshop agenda, the guiding document for breakout groups, a list of workshop participants and contact information, and a photograph of participants.

These proceedings are meant to be a synopsis of the workshop and its findings. Presenters have sole responsibility for the views and data in their presentations. The content of presentations and summaries from breakout sessions does not necessarily reflect the views of the National Oceanic and Atmospheric Administration nor those of the University of Washington Tacoma.

TABLE OF CONTENTS

PREFACE 4

TABLE OF CONTENTS 5

EXECUTIVE SUMMARY 7

PRESENTATIONS 18
Opening Remarks 19
Keynote Address – How concerned should we be about microplastics?
Dr. R.C. Thompson 22

Session I: Occurrence of small plastic debris in the marine environment 77
Fate of plastics debris in the marine environment
Dr. Anthony Andrady 78
Microplastics as accumulators and sources of persistent organic pollutants in marine food webs: how significant?
Dr. Alan Mearns 107
The oceanography, biology, and fisheries of the North Pacific
Dr. Michael Seki 162
Small plastic debris and plankton: perspectives from NOAA plankton sampling programs in Northeast Pacific ecosystems
Dr. Miriam Doyle 186

Session II: Impact of small plastic debris on the marine environment 226
Foolish fulmars and their contribution to ecological quality
Dr. Jan A. van Franeker 227
Incidence of marine debris ingestion in seabirds from Midway Atoll and Heard Island
Dr. Heidi J. Auman 254
Ingestion of microplastics by marine invertebrates
Dr. Richard Thompson 295
Translating scientific findings into action: California's response to plastics in the environment
Dr. Stephen Weisberg 326

Session III: Impacts of small plastic debris exposure to persistent organic pollutants 351
Effect of sorbent particulate amendments on PCB bioavailability in sediments
Dr. Upal Ghosh 352
International Pellet Watch: Global distribution of persistent organic pollutants (POPs) in marine plastics and their potential threat to marine organisms
Dr. Hideshige Takada 371
Microplastic-pollutant interactions and their implications in contaminant transport to organisms
Dr. Emma Teuten 429

Session IV: Effect of oceanic small plastic debris on biogeochemical cycling of POPs 458
Role of microplastics on transport and fate of POPs
Dr. Rainer Lohmann 459
Wrap-up: Consequences and challenges of microplastics in the world's oceans
Dr. Joel Baker 510

APPENDICES 518
A.Workshop Agenda 519
B. Charge to Breakout Groups 521
C. Workshop Participants 522
D. Group Photograph 528

EXECUTIVE SUMMARY

Summary of the *International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris*

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Executive Summary

Are microplastics a problem in the marine environment? This was the key question investigated at the microplastic marine debris research workshop. Participants examined information on a variety of topics that addressed sources, transport, and possible impacts of microplastic marine debris. When planning this workshop, it was sought to bring together leading scientists investigating microplastics as well as those with expertise in related fields. Very little research directly focusing on sources and levels of microplastics in the marine environment has been published, and even less published research addresses the impacts of microplastics on marine ecosystems. This workshop opened the dialog among scientists in this field and took a comprehensive look at each component of the issue: sources and occurrences of microplastics, impacts of microplastics on the marine environment, and chemistry of microplastics including their ability to sorb and leach contaminants in the marine environment.

I. Workshop Summary

Session I. Occurrence of small plastic debris in the marine environment

Session I presentations covered a broad overview of microplastics in the environment; the fate of plastic debris in the environment; potential approaches to identifying impacts on marine food webs; the oceanography of the North Pacific Ocean; the interaction of oceanography, biology and fisheries; and how these factors may affect movement of microplastics. Additionally, the results of plankton survey cruises in the eastern North Pacific that incidentally captured microplastics (*e.g.*, California Cooperative Oceanic Fisheries Investigations) were discussed (Doyle 2009*)*. These presentations gave an extensive overview of the problem of documenting occurrences, especially in the open ocean. No research has examined microplastics in deep ocean sediments, and most has only – quite literally – scooped the surface of the ocean looking for plastics. Though

many plastics are buoyant, many other factors play a role in the "life cycle" of a piece of plastic in the ocean. Sinking may occur due to biofouling, and plastics may eventually settle into sediments. The fouled microplastics may be eaten, the biofilm consumed, and the remaining undigested plastic packaged into fecal matter. Oceanographic factors are very important controls of the movement and weathering of plastic particles, as is the chemical composition and durability of the plastics (Andrady *et al.* 1998; Pichel *et al.* 2007). It is likely that nearly all of the plastic that has ever entered the environment still occurs as polymers and very little or any plastic fully degrades in the marine environment (Andrady 2009). Estimates of amount of macro- and microplastic in the oceans, both in absolute quantities and relative to plankton, are highly uncertain due to the lack of consistent, verified sampling and analytical methods (Carpenter *et al.* 1972; Colton *et al.* 1974; Day and Shaw 1987; Moore *et al.* 2001; Thompson *et al.* 2004). A risk assessment framework was applied to the microplastics issue in an effort to enhance discussion on the best practices to further the science of microplastics (Mearns 2009). This first session framed the complex issues surrounding the occurrence and sources of microplastics for the workshop participants, and set the stage for discussion to identify information gaps and needed studies.

Session II. Impacts of small plastic debris on the marine environment

Session II highlighted the paucity of data linking microplastic debris to demonstrated impacts on the marine environment. Quite a bit of research has focused on larger plastic items that are ingested by seabirds during oceanic foraging trips, but these pieces are greater than 10cm along the longest dimension and too large to be considered "microplastics" (*e.g.*, Auman *et al.* 1997; Baltz and Morejohn 1976; Fry *et al.* 1987; Kenyon and Kridler 1969; Pettit *et al.* 1981; Ryan 1988; van Franeker *et al.* 2004, 2005). Research on northern fulmars, albatross, and other seabirds was presented at the workshop. Some connections were drawn between ingestion of microplastics and seabird death, but overall the impact on entire seabird populations is either unknown or not considered to be large enough to warrant further investigation at this time (Auman 2009; Mallory *et al.* 2006; van Franeker 2009). One presentation given in this session discussed the results of a laboratory study that surveyed the ability of several marine invertebrates to ingest microplastics. The lugworms, amphipods, barnacles, and mussels all were capable of ingesting and passing microplastics through their digestive systems, even though each has a different mode of feeding and particle selection (Browne *et al.* 2008; Thompson *et al.* 2004). Another presentation in this session stressed a comprehensive and scientific approach to the microplastics issue in order to give policymakers the best information possible on the current status of microplastics (Weisman 2009*)*. Data that conclusively demonstrate negative impacts of microplastics on the marine environment are not available. This is probably the largest and most critical gap to fill. Research into collection methods, species impacts, and removal methods should focus on potential microplastics hotspots.

Session III. Impacts of small plastic debris exposure to persistent organic pollutants (POPs)

Session III provided an overview of the interaction of microplastics with persistent organic pollutants (POPs). A synopsis of organic pollutant behavior in the environment was presented, including the process of adding highly sorptive particles to contaminated sediments as a remediation technique (Ghosh 2009). Two presentations detailed the occurrence and potential implications of POPs sorbed to plastics (Takada 2009; Teuten 2009). In some areas, the pollutants sorbed to plastics mirror the concentrations of these pollutants found in mussels from the same areas (Takada 2009). In a laboratory environment, phenanthrene was sorbed from dosed sediments to microplastics and in a separate experiment, ingestion of microplastics was documented in three species of sediment-dwelling invertebrates (Teuten *et al.* 2007; Thompson *et al.* 2004). To date, only a few types of plastic polymers and a few types of organic pollutants have been examined (Endo *et al.* 2005; Karapanagioti and Klontza 2008; Mato *et al.* 2001; Rios *et al.* 2007; Teuten *et al.* 2007). The specificity of pollutant and plastic interactions warrant further research into the ability of plastics to not only sorb contaminants from the environment, but also leach contaminants to the marine environment and to organisms upon ingestion.

Session IV. Effects of marine microplastic debris on the biogeochemical cycling of persistent organic pollutants

Session IV reviewed the global cycling of persistent organic pollutants in marine environments, focusing on the implications of microplastics sorbing POPs and leaching contaminants to the marine environment. Based on available information, it seems unlikely that the amount of microplastics in the marine environment is currently large enough to be an important geochemical reservoir for POPs, as research was presented that pointed to a much stronger binding of organic pollutants to the more abundant black carbon than to plastic polymers (Lohmann 2009). However, depending on the amount of microplastics and their life cycle in the oceans, it is possible that these sorptive properties could influence parts of POPs' biogeochemical cycles. Attention must also be paid to the scale of the system; small scale marine environments may differ from the global perspective. Determining the mobility of sorbed pollutants and of labile plastic components is key to addressing the risk that microplastics pose to food webs and biogeochemical cycles on both regional and global scales.

II. Findings

After the workshop sessions, a Steering Committee, which consisted of the leaders of the breakout groups, members of the NOAA Marine Debris Program, and the meeting coordinators, met to review the information exchanged and discussed at the workshop and to write the Executive Summary. The workshop participants agreed that microplastics may pose problems in the marine environment based on the following: (1)

the documented occurrence of microplastics in the marine environment, (2) the long residence times of these particles (and, therefore, their likely buildup in the future), and (3) their demonstrated ingestion by marine organisms. Microplastics are present in the marine environment, originate from a variety of sources, and are persistent in the marine environment (Andrady *et al.* 1998). Impacts of microplastics to organisms and the environment are largely unknown. The ability for plastics to transport contaminants has been documented, but the specifics of sorption and leaching are not fully understood (Endo *et al.* 2005; Karapanagioti and Klontza 2008; Mato *et al.* 2001; Rios *et al.* 2007; Teuten *et al.* 2007). It is difficult to determine how large an impact microplastics might have as sources or sinks of these pollutants to the oceans. Altogether, the science suggests that microplastics deserve further scrutiny in the laboratory and in the field. Collaborations should be utilized, and research is needed to (1) determine a "life cycle" of microplastics for different marine environments, and (2) assess the ecosystem-level impacts of microplastics on the marine environment. Only then will it be possible for the best science to inform management decisions for the remediation and prevention of microplastic pollution in the marine environment.

Key Issue #1. Sources of microplastics to the marine environment

Points of agreement

Definition of microplastics. The Workshop participants defined microplastics as plastic particles smaller than 5mm.

While there is no requirement for a "lower bound" in size, as a practical matter defining microplastics as those that range between 5mm and 333µm recognizes the common use of 333µm mesh neuston nets commonly used in the field to capture plankton and floating debris. Smaller (1.6µm) particles have been detected, but no standard procedure for sampling these in seawater has been developed (Ng and Obbard 2006). The maximum size was chosen to focus the microplastics discussion on possible ecological effects other than physical blockage of gastrointestinal tracts. Though "micro" infers the need for microscopy to view these plastic pieces, due to the early state of research the Steering Committee chose not to exclude visible components of the small plastic spectrum and thus set the upper limit at 5mm. Perhaps when the science advances, "small plastics" that can be seen without the aid of microscopy will be assigned to a separate category and only microscopic polymer fragments will be included as "microplastics."

Sources of microplastics. An important outcome of the workshop is that there are two main types of sources of microplastics. Borrowing terminology from atmospheric sciences, "primary" microplastic sources are those in which microplastics are intentionally produced either for direct use or as precursors to other products. Examples include pre-production plastic pellets, industrial abrasives, exfoliants, plastics used in rotomilling, and other consumer product

uses. "Secondary" microplastics are formed in the environment from breakdown of larger plastic material, especially marine debris. The rate of production of secondary microplastics likely depends on characteristics of the plastic, the extent of weathering, and on the energetics of the local environment.

Key information gaps

The relative importance of primary and secondary sources of microplastics to the marine environment is unknown. It is important to begin addressing this gap in order to mitigate and eventually prevent the input of microplastics into the marine environment, keeping in mind that control strategies will differ by source (e.g., disintegrating plastic debris vs. spillage of pre-production plastic pellets). Obviously, the absolute and relative magnitudes of these source types will vary considerably in space and time.

The physical and chemical composition of primary microplastics and their production volumes has not been cataloged in a way that allows their potential importance to be estimated. Weathering characteristics of primary microplastics, especially release of component chemicals, are largely unstudied.

Predicting the rate of secondary microplastic production is very difficult, as no systematic study of the disintegration processes of microplastics under realistic conditions has been conducted.

At present there are no methods to characterize microplastic particles by source location, although initial efforts to characterize particles by polymer type using Fourier Transform Infrared Spectroscopy (FT-IR) are promising (Thompson *et al.* 2004).

Next steps

Complete an inventory of primary microplastic production and use. This inventory should catalog production by region (*e.g.*, North America), by composition, and by use (*e.g.*, abrasives, consumer products, rotomilling).

Complete an inventory of secondary plastic production and release to the marine environment.

<u>Key Issue #2. Measuring microplastics in the marine environment</u>

Points of agreement

At present, progress is limited by the lack of consistent methods to collect, isolate, identify, and quantify microplastic particles in marine samples (water, sediments,

and organisms). Methods to consistently analyze and report data are also required.

Initial measurements of microplastics levels in the marine environment are too sparse to make general statements about spatial distributions or temporal trends.

Key information gaps

Methods to isolate microplastics from surface waters (net tows, filters), sediments, and organisms are desperately needed before further progress can be made in this field. Current methods are tedious and labor-intensive and may be biased towards microplastics that are clearly different from the surrounding natural particles (Thompson *et al.* 2004). These methods likely underestimate levels of smaller and neutrally colored microplastics.

There has not been any attempt to compare or intercalibrate methods used by the very few research groups around the world measuring microplastics in the marine environment.

Next steps

Further evaluate, standardize, and compare sampling and analytical methods among independent laboratories. Conduct an initial investigation in which surface waters, sediments, and native deposit- and filter-feeding organisms are collected from two or more likely "microplastic hot spots" and exchanged between laboratories. Such a study would lead to improved and standardized methods, which could then be expanded to a larger interlaboratory comparison exercise.

Where possible, add microplastic measurements to existing and ongoing plankton surveys, especially in coastal areas.

<u>Key Issue #3. Routes of exposure and potential vulnerabilities</u>

Points of agreement

Studies by R. C. Thompson, University of Plymouth, and colleagues demonstrate that microplastic particles are ingested by deposit-feeding benthos and by filter-feeding mussels, and that microplastics can be assimilated within the mussel (Browne *et al.* 2008; Thompson *et al.* 2004).

Marine organisms that ingest particles of the size range of microplastics are the most vulnerable to potential impacts and should be the focus of initial studies.

Key information gaps

To date, only one study has examined the possible interactions between marine zooplankton and microplastics (Andrady 2009). In a laboratory study presented at the workshop, Andrady and colleagues showed ingestion of 20μm polyethylene fragments by the krill species *Euphasia pacifica*.

To date, no studies have examined microplastic interactions between larval fish or pelagic tunicates, many of which inhabit the sea-surface microlayer, and microplastics. These interactions may be especially important to those species that utilize coastal habitats for spawning.

Next steps

Based on known behaviors, identify marine species or life stages that would likely be most vulnerable to microplastic exposure.

Since there are a very large number of possible combinations of particle-feeding species and microplastic types, focus initial exposure studies on field studies in locations that are likely "microplastic hotspots" and are habitat for vulnerable species and sensitive life stages. Document whether microplastics are ingested by these species under field conditions.

<u>Key Issue #4. Effects of microplastics on marine organisms</u>

Points of agreement

Possible effects include three broad modes of action: (1) physical blockage or damage of feeding appendages or digestive tract, (2) leaching of plastic component chemicals into organisms after digestion, and (3) ingestion and accumulation of sorbed chemicals by the organism. All of these effects require that the microplastic particles be ingested.

Microplastics as defined here (<5mm) are not likely to cause widespread ingestion-related effects on large organisms (*e.g.*, birds, marine mammals), certainly relative to the well-documented impacts of larger marine plastics.

Key information gaps

Dose-response relationships between specific types of microplastics and vulnerable marine species or life stages do not yet exist.

Protocols for conducting realistic exposure experiments of microplastics in laboratory toxicity studies are needed.

Next steps

Scale direct toxicity studies to levels of microplastic particles observed in hotspots, using likely vulnerable organisms as described above.

Key Issue #5. Roles of microplastics on the cycling of persistent organic pollutants (POPs)

Points of agreement

At current levels in the open ocean, microplastics are unlikely to be an important global geochemical reservoir for historically released POPs such as PCB, dioxins, and DDT. It is not clear if microplastics play a larger role as chemical reservoirs on smaller scales.

POPs have a high affinity for plastic in seawater. This is the basis for several POP sampling techniques, including passive sampling. While this high affinity results in elevated POP concentrations on microplastic particles, these POPs may not be readily bioavailable.

Key information gaps

Very little is known about the chemical composition and rates of leaching of integral plastic components in seawater. It is not possible, therefore, to judge whether emission of primary microplastics is a significant source of, for example, plasticizers or flame retardants to the world's oceans.

While microplastics accumulate POPs and some organisms ingest microplastics, the net effect of this on transfer of POPs into marine organisms is unclear. On one hand POP ingestion is increased, but it is not clear under what physiological conditions plastic-associated POPs would be assimilated by marine organisms upon ingestion of plastics.

Next steps

Based on the inventory of primary microplastic production (see Key Issue #1, next steps), conduct studies of integral plastic component leaching in seawater to enable estimates of component loadings to the marine environment.

Systematically study the role of microplastic ingestion in POP exposure (in both the water column and sediment) with a strategically selected series of microplastics (varying in magnitude of affinity for POPs), set of POPs (with varying aqueous solubilities), and organisms (filter feeding and deposit feeding). Interpret results from these studies using existing pharmacokinetic models that account for ingestion rates and assimilation efficiencies.

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ABSTRACTS AND PRESENTATIONS

International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris

NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
Marine Debris Program

UNIVERSITY OF WASHINGTON TACOMA
The Center for Urban Waters

Joel E. Baker, PhD

September 9-10, 2008

University of Washington Tacoma
1900 Commerce St.
Tacoma, WA 98402-3100

Why are we here?

1. To fully explore what is <u>currently</u> known about microplastics in the oceans
    1. Where do they come from?
    2. How do they vary in space and time?
    3. How do they affect marine organisms?
    4. How do they impact cycling of chemical contaminants
2. To identify gaps in our knowledge, needs for technology development, and opportunities for collaboration
    1. Links between sources and distribution
    2. Measurement tools and predictive modeling
    3. Dose-response relationships
    4. Risk-based analysis framework
    5. International collaboration

Why are we here?

3. To explore synergies between marine plastics and marine persistent organic pollutant (POPs) research

    1. Are microplastics ‘small bits’ or ‘big chemicals’?
    2. How do concepts of ‘persistence’ and ‘global transport’ apply to microplastics?

4. Challenges

    1. How is the microplastic issue different from ‘macro’ plastics?
    2. How do we advance the science beyond observations to understanding?

5. Workshop Products

    1. Publication of ‘state-of-the-science’ white paper in a peer-reviewed journal
    2. Consensus statement of research gaps and opportunities

Keynote Address - How concerned should we be about microplastics?

Dr. RC Thompson, University of Plymouth, Plymouth, UK

Abstract: Microplastics are small fragments of plastic debris. This material has been reported on shorelines and in the water column on a global scale and there are concerns it may present hazards to wildlife and to human health.

Methods to separate and quantify microplastics from environmental samples are time consuming and represent an incomplete estimate of contamination; however these semi-quantitative approaches have successfully identified microplastic as small as 20μm in diameter, have shown that the abundance of this debris has increased over recent decades and that microplastics are widely distributed in the environment. The sources of microplastic debris are most probably fragmentation of larger items of marine litter and the direct release of small pieces of plastic from various cleaning applications.

Plastic products bring many societal benefits and as a consequence, annual global production has increased from 5 million tonnes in the 1950s to over 230 million tonnes today. However, because of their disposable nature substantial quantities of plastic items have been discarded to the environment and so the abundance of microplastic is likely to increase over the next few decades.

Laboratory experiments have shown that microplastics are ingested by filter feeders, deposit feeders and detritivores and there is concern that ingestion of this material could present a physical hazard to wildlife, for example by compromising the ability to feed. In addition, there is evidence, that small fragments of plastic could facilitate the transfer of toxic substances to wildlife. Two routes have been suggested: (1) the release of chemicals incorporated during manufacture as plasticisers, flame retardants and antimicrobials, and (2) the release of persistent organic pollutants (POPs) that have arisen in the environment from other sources and have sorbed to plastic debris in seawater.

Reaching robust, environmentally relevant conclusions about the abundance and the potential impacts of microplastic debris is not a trivial task and this workshop offers a major step toward identifying a suitable research agenda. There is also an important need for parallel research and policy focusing on solutions to established problems associated with the production, usage and disposal of plastics.

Richard C. Thompson, PhD, is a Marine Ecologist specialising in the ecology of shallow water marine habitats. He studied Marine Biology at the University of Newcastle upon Tyne from 1988 to 1991 followed by a PhD on the ecology of intertidal biofilms at the University of Liverpool from 1992 to 1996. He subsequently worked as postdoctoral research fellow at the University of Southampton and since 2001 he has been a lecturer, and is now a Reader, in Marine Ecology at the University of Plymouth. He currently leads the BSc Marine Biology degree programme at Plymouth and lecture in marine ecology and experimental biology. His research has focused on a wide range of 'natural' ecological interactions and on anthropogenic disturbance. He supervises a research group of 2 post docs and 8 PhD students. Work by his group has examined: biodiversity and ecosystem function using rockpools as natural mesocosms, trade-offs between food availability and refuge quality, trophic linkages between intertidal and subtidal habitats, the ecology of coastal defenses and marine renewable energy developments. Much of his work over the last decade has focused on marine debris. In 2004 his group published a paper in *Science* describing the distribution and temporal trends in the abundance of microscopic fragments of plastic in the NE Atlantic. They have subsequently been working to establish the environmental consequences of this type of debris. He is currently acting as invited editor of a Theme Issue of 13 papers, for Philosophical Transactions of the Royal Society, focusing entirely on Plastics the Environment and Human Health.

How concerned should we be about microplastics?

Dr Richard Thompson

University of Plymouth UK

This presentation as given during the workshop contained unpublished data whichhas been deleted form the slides that follow here

How concerned should we be about microplastics?

Globe & Mail 17/11/07

A toxic Trojan horse: Tiny plastic particles pack a major punch

ZOE CORMIER
zcormier@globeandmail.com

MICROPLASTIC UNFANTASTIC

THE NEWS The planet's oceans are full of plastic trash that has broken down into microscopic particles. These "microplastics" are impossible to clean up. And now research suggests they act like tiny Trojan horses

cy has embraced recommendations to cut both nitr gen and phosphorous. But there is currently no deadl to put that plan into action. And no move to counter the production of what Prof. Scavia calls "political holy water." President Gec W. Bush has called for 35 ethanol by 2

HOPE FOR

THE NEWS ings of L third run port – w double

New York Times 30/10/07

Even Tiny Plastic Pieces Can Carry Pollution Throughout the Oce

To marine biologists, "plas a dirty word. Fish and bir eat or become tangled in gear or other plastic flo

Guardian, UK 27/2/08

Haul aboard

The discovery of large amounts of microplastic in remote seas suggests marine pollution is at worse levels than previously thought

er

sea of rubbish – dubbed the grea bage patch, and which may contain tonnes of flotsam – swirls around in a tem of currents known as the North Pac Gyre, a large amount of microplastic w expected; indeed, the highest concentra tions were found there. But Esperanza also discovered an unexpectedly high number of particles in the Atlantic, around the Canary Islands and the Azores. The haul of microplastic continued in the Mediterranean, the Red Sea, the Indian Ocean, in the Bay of Bengal, and off Malaysia and the Philippines. Only in the furthest reaches of

Western Morning News 13/12/06

World's oceans 'may be poisoned by plastic'

MICROSCOPIC particles of plastic could be poisoning the oceans, according to a team of researchers in Plymouth.

They report that small plastic pellets called "mermaid's tears", which are the result of industry and domestic waste, have spread across the world's seas.

The scientists are worried that water and what effect it is having on the marine environment.

He and his team set out to find out how small these fragments can get.

So far, they have identified plastic particles of around 20 microns – thinner than the diameter of a human hair.

In 2004, their groundbreaking

Microplastics

- What are they
- Historical perspective on plastic fragments
- Collection, separation and identification
- Distribution and temporal trends
- Potential sources of microplastic debris
- Potential consequences
- Research priorities
- Bigger picture

Familiar types of debris

Disposable packaging, rope, netting

Less familiar – Mega debris!

Less familiar small debris

Plastic fragments

Micro debris next to sand grain

What is microplastic debris ?

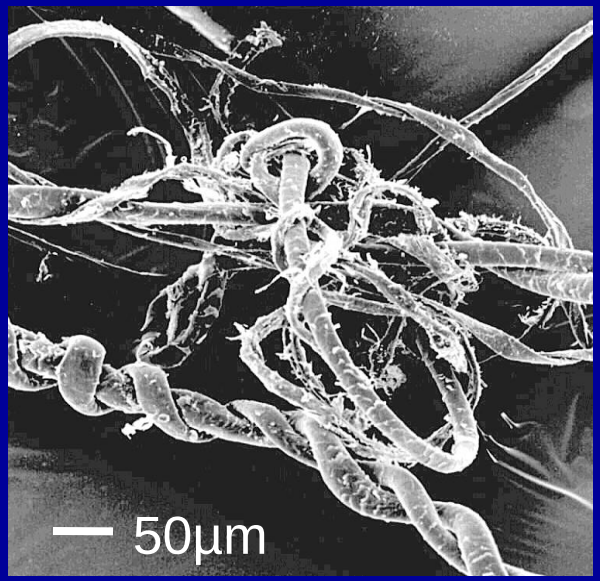
Part of a continuum - small end of the debris size distribution

Ribic *et al.* 1992 < 5mm

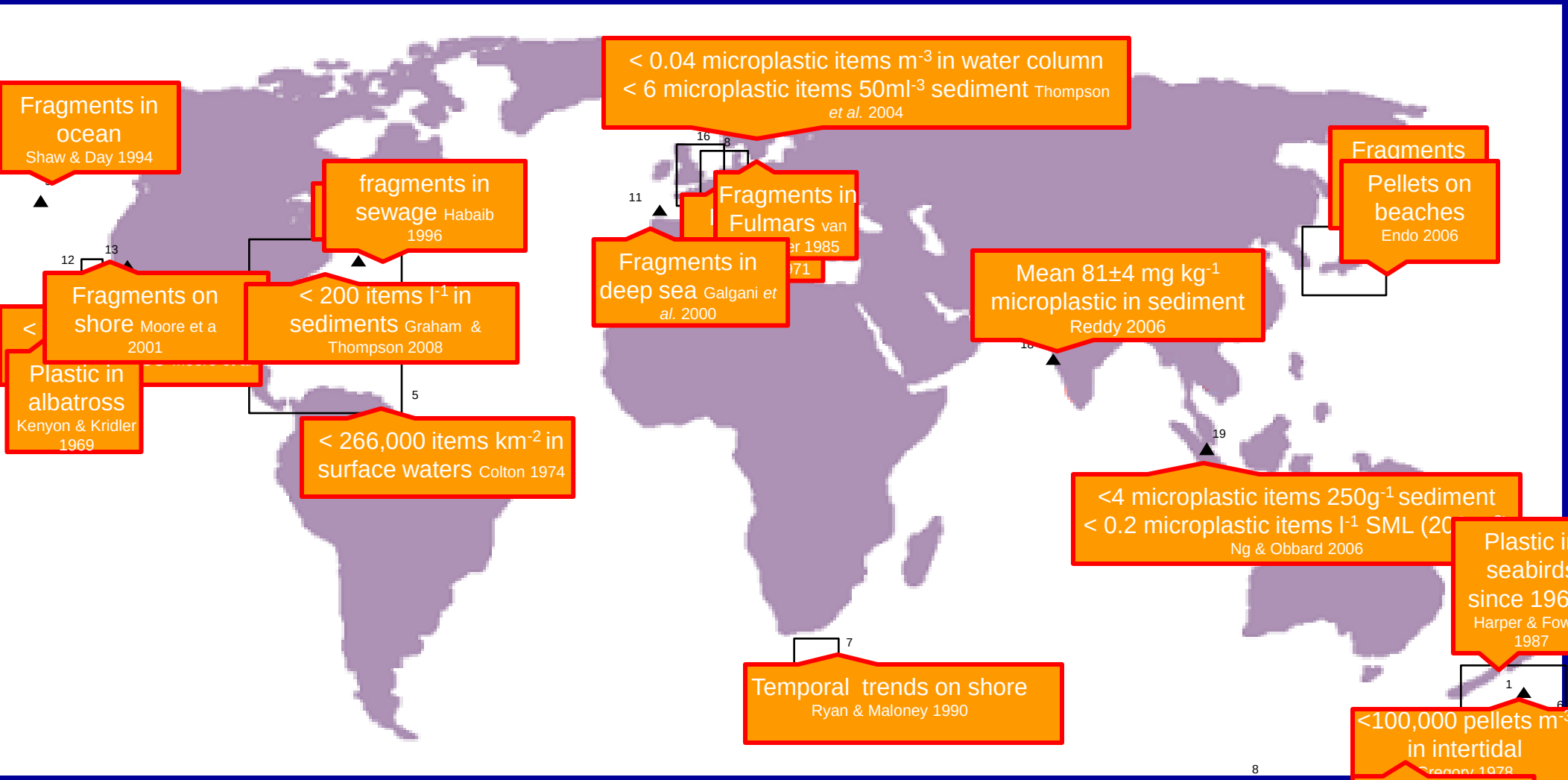
Thompson *et al.* 2004 fragments visible with x30 microscope >20µm

Browne *et al.* 2007 suggest microplastic defined as <1mm

Smallest reported fragments 1.6µm (Ng & Obbard 2006)



Selection of published reports of small plastic fragments and pellets



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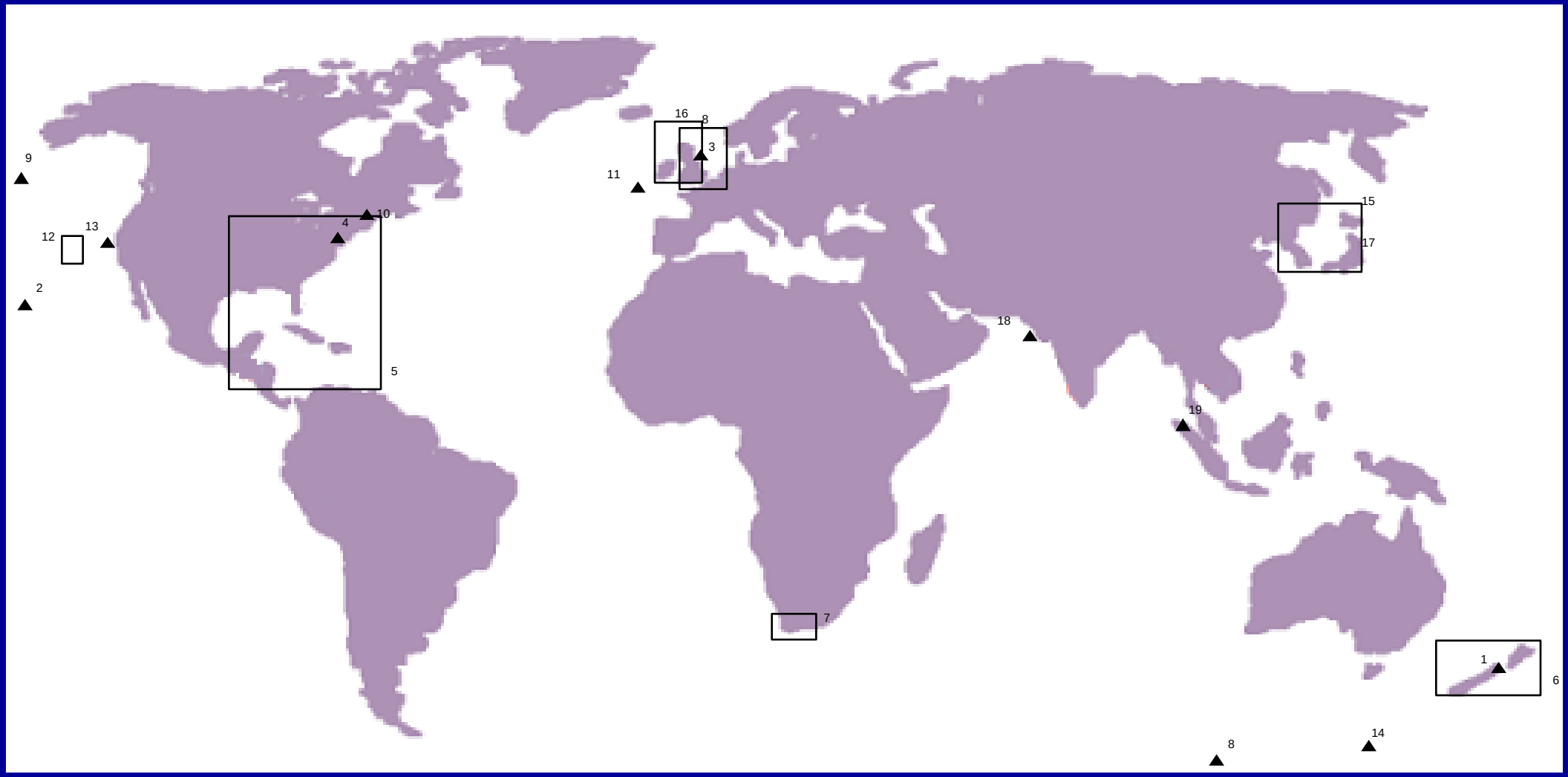
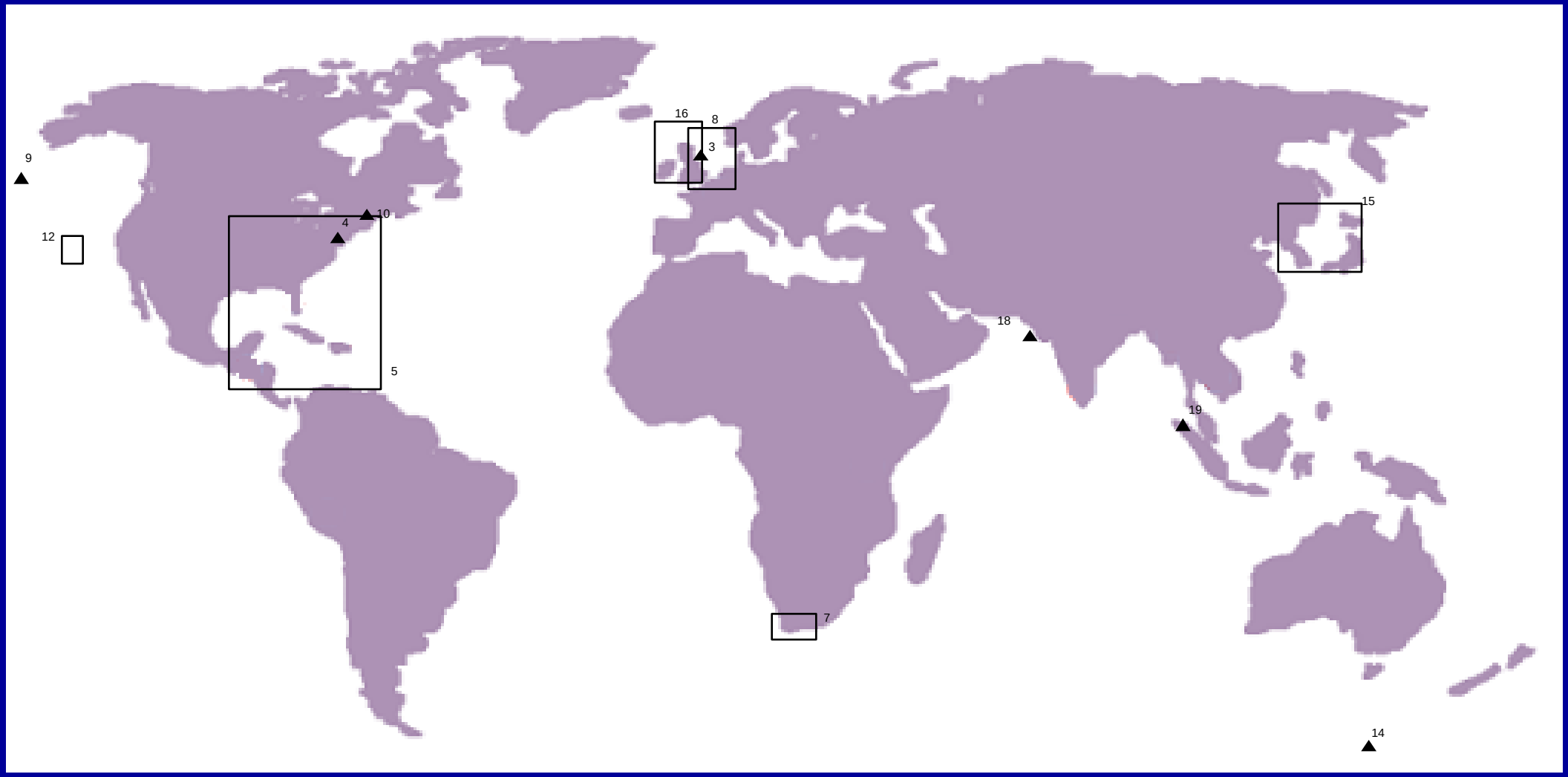


Published reports of microplastic ≤ 1mm



Collection, separation from sediment and identification

1. Sediment collected from strandline (5 replicate 250ml samples)
2. 50ml portion of each sample transferred to separating funnel
3. concentrated NaCl solution added (tried KCl but rejected)
4. Shaken
5. Supernatant (buoyant material) filtered
6. Repeat steps 3 and 4 to give sequential extractions (n=3)
7. Run control extractions without sediment
8. Filter papers examined under low power microscopy
9. Pieces with uncharacteristic appearance removed for identification (tried digestion of natural organics with conc HNO_3 but rejected)
10. Identification (FT-IR)

Identification of small debris

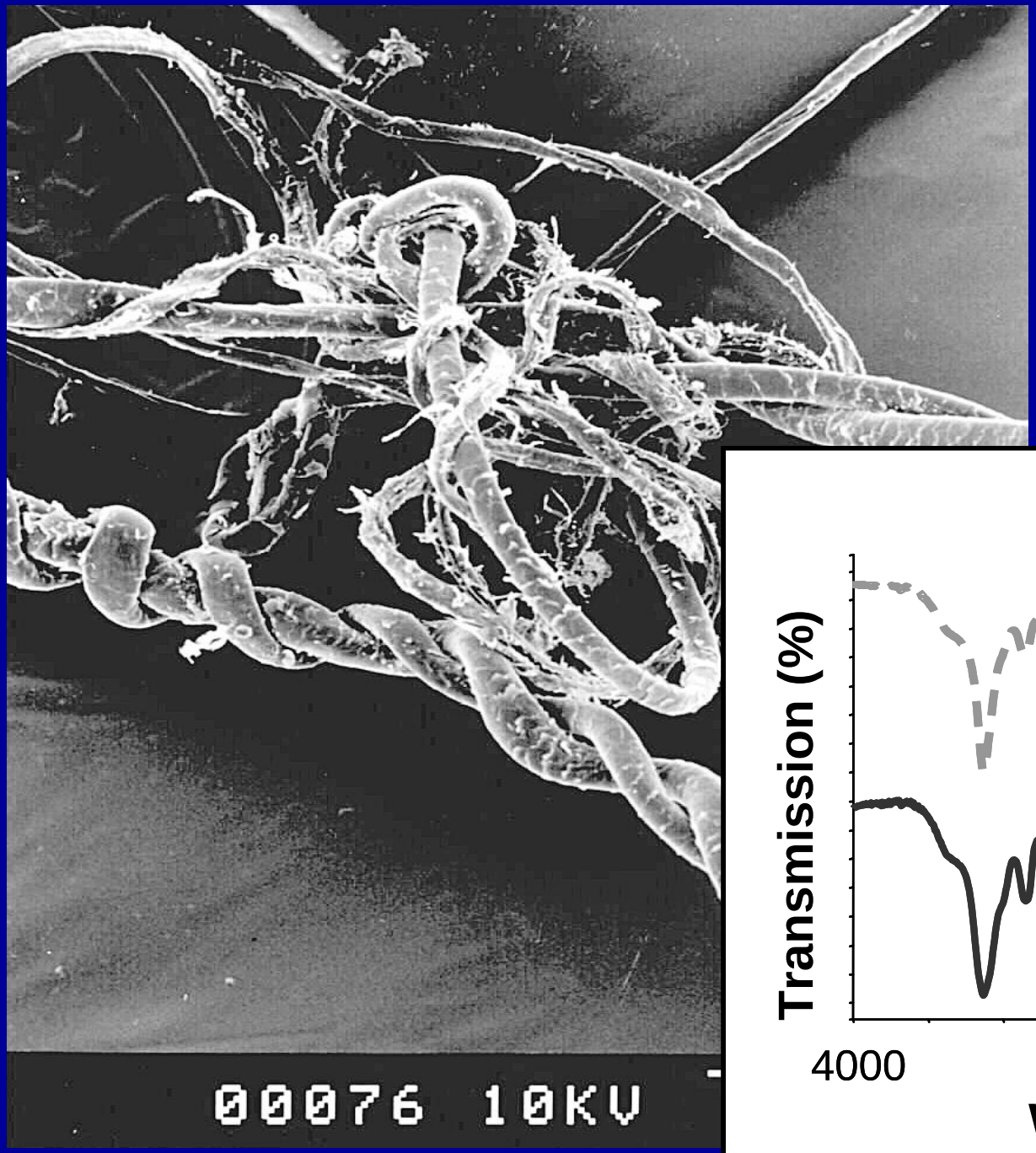
FT-IR spectroscopy - match unknown fragments against polymer data base

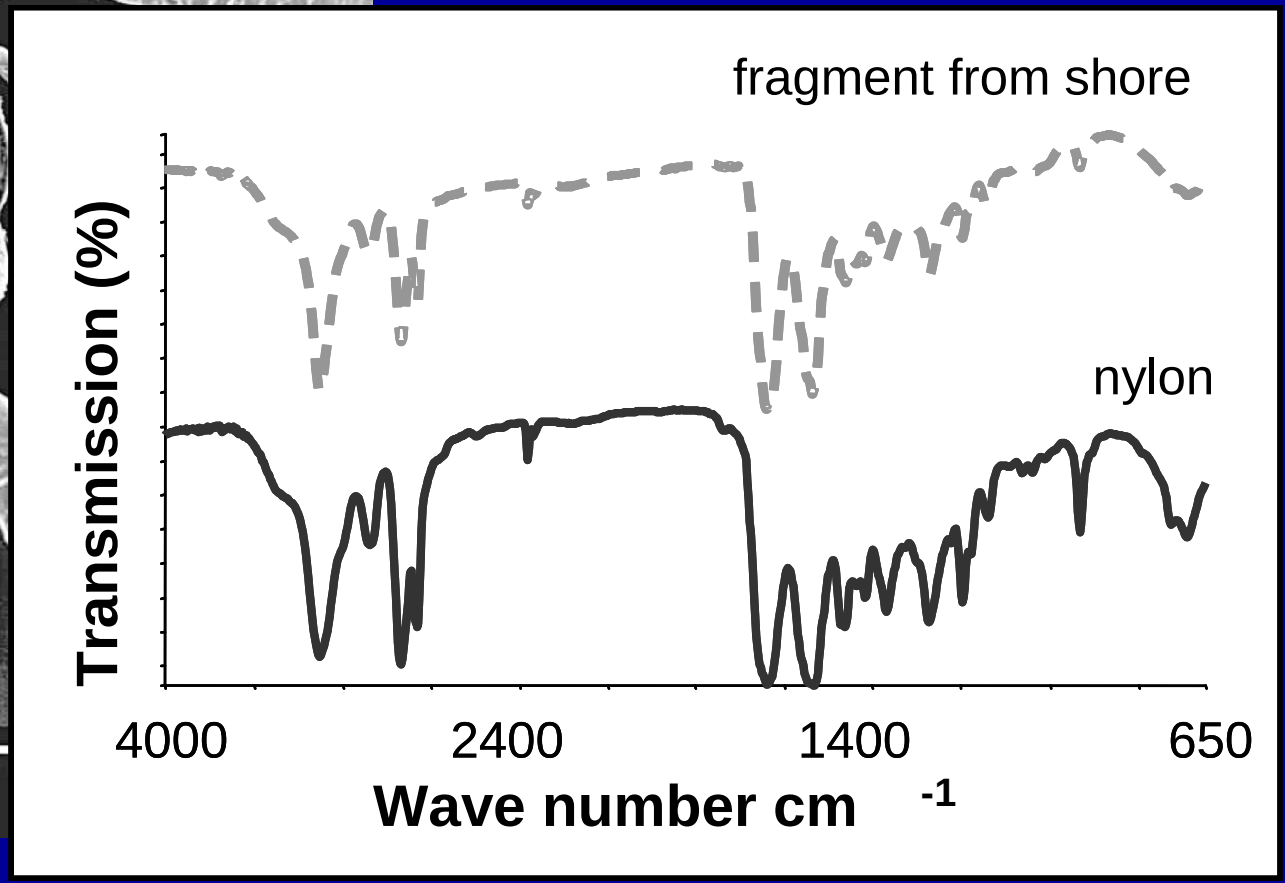
Microplastic debris

smallest pieces identified
as plastic 1.6µm

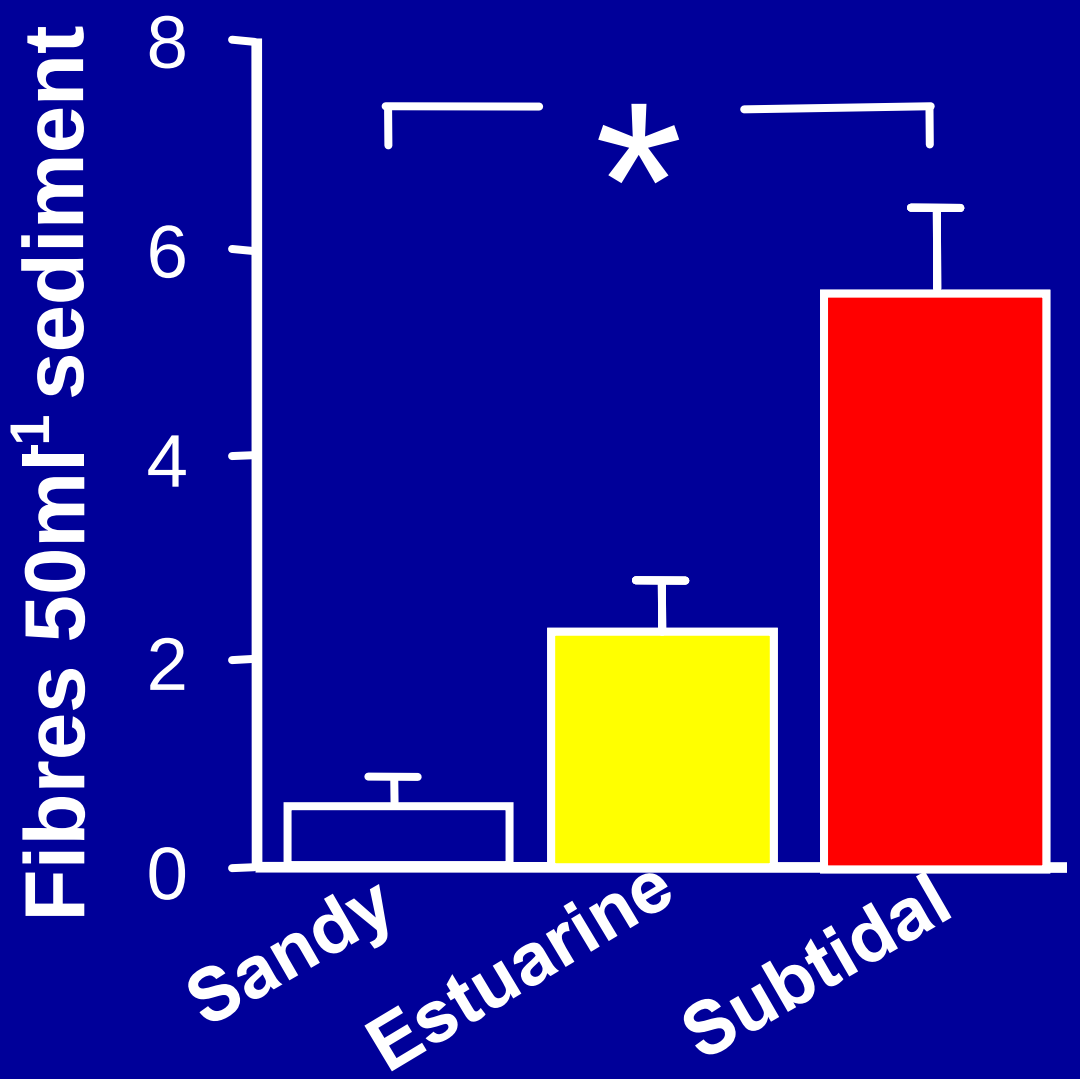
⅓ plastic, ⅓ natural debris

⅓ unknown, Rayon?



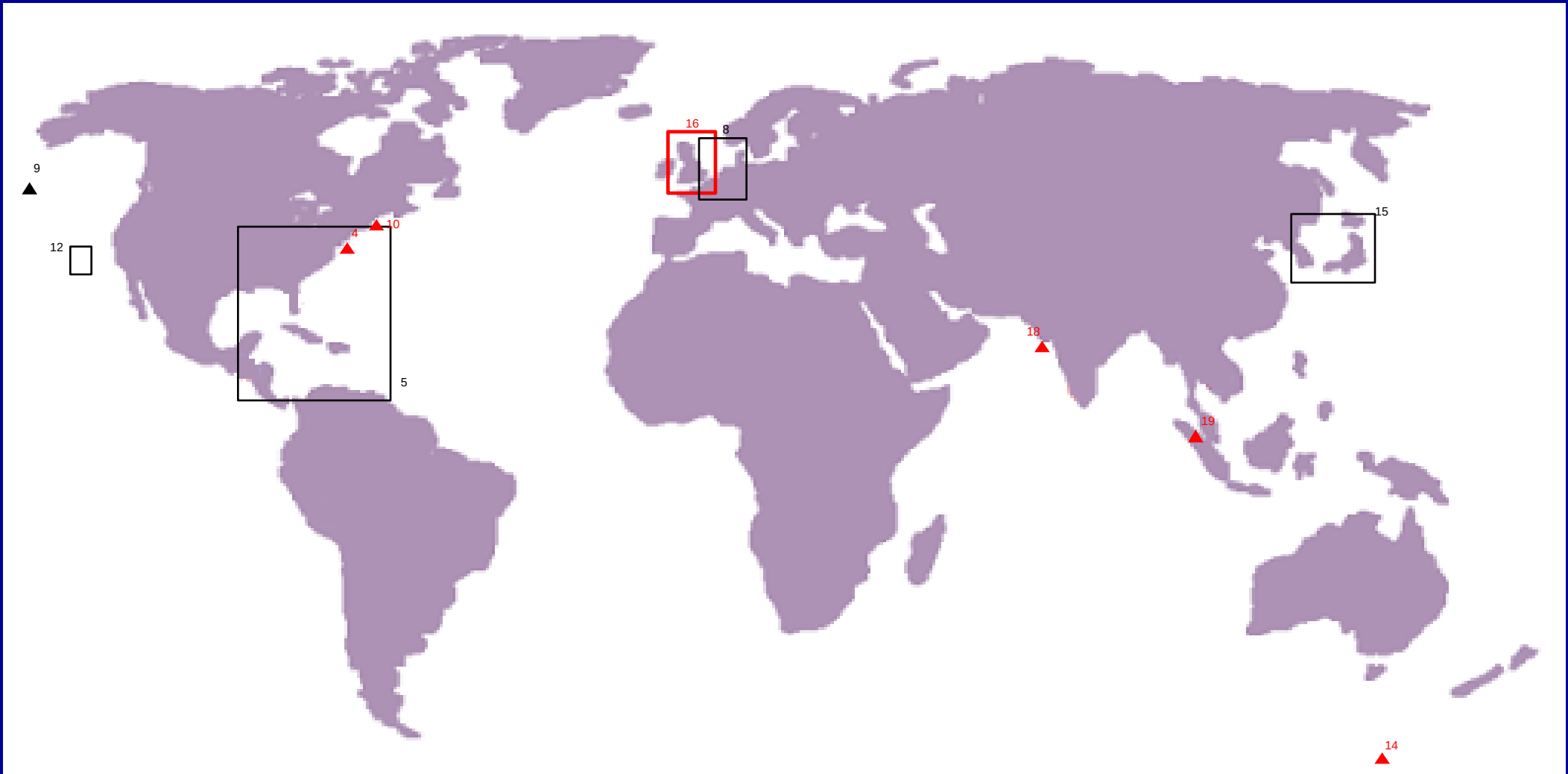


Distribution of microplastic in sediments, UK



Thompson *et al.* 2004, *Science*

Microplastic ≤ 1mm identity confirmed by FT-IR



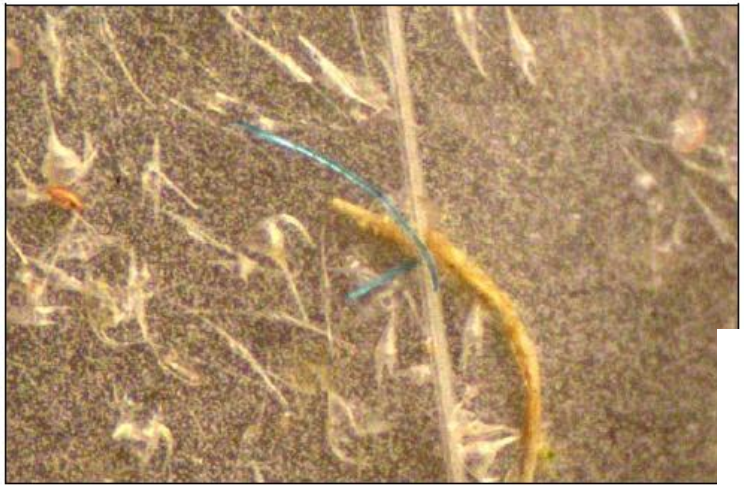
Microplastic ≤ 1mm identity confirmed by FT-IR

This slide contained unpublished data showing global distribution of microscopic fragments on shorelines Thompson et al. Unpublished data

(other recent unpublished data from US and Belgium, European Plastic Federation – not shown)

This slide contained unpublished data showing global distribution of microscopic fragments on ocean surface Thompson et al. Unpublished data

Small plastic particles in Coastal Swedish waters.



Blue plastic fibre, diameter ~20µm

KIMO Sweden

Table 1 Number of plastic particles concentrated with 80µm plankton net

	The amount of particles in number per m³					
	Red fibres	**Blue fibres**	**Black / transp.**	**Milky-white spheres**	**Σ particles per m³**	**+/- sd**
Lysekil, Southern harbour	50	1 900	450	0	2 400	
Lysekil, Southern harbour, inner harbour	100	550	500	0	1 150	
Lysekil, Southern harbour, nrthern Släggö	50	350	200	0	600	
Lysekil, outer Släggö	50	100	50	0	200	
Björkö harbour, mean of 2 samples	0	400	250	0	450	283
Björkö ferry,mean of 3 samples	0	200	100	0	167	126
Tjuvkils huvud, harbour	50	200	0	0	250	
Stenungsund, location 3	25	0	25	1 575	1 625	
Stenungssunds leisure-boat harbour	50	150	50	850	1 100	
Stenungsund, location 4	50	300	50	750	1 150	
Stenungsund, industrial harbour	0	150	0	102 400	102 550	
Lysekil, Gäven-Byxeskär	80	120	320	40	560	
Lysekil, Gäven	70	160	80	0	310	

Summary

KIMO Sweden has given *N*-research an assignment to perform a pilot-study to assess the abundance of small, microscopic, plastic particles in Swedish west coast waters. *N*-research has taken water samples from nineteen locations, both planktonic and from benthic sediments, and conducted analyses thereof.

In this pilot study we found:

- There is a considerably higher amount of small plastic particles when using an 80µm mesh to concentrate the water samples. Up to 100 000 times higher concentrations of small plastic fibers was retained on a 80µm mesh compared to a 450µm mesh
- The amount of plastic particles, concentrated with a 80µm mesh net, was in the range of 150 – 2400 per m^3
- The amount of plastic particles, concentrated with a 450µm mesh net, was in the range of 0,01 – 0,14 per m^3 which is comparable to earlier surveys (0,01 – 7 per m^3).
- A very high concentration, 102 000 per m^3 of plastic particles (diam. ~0.5 - 2mm) was found locally in the harbour outside a polyethene production plant.

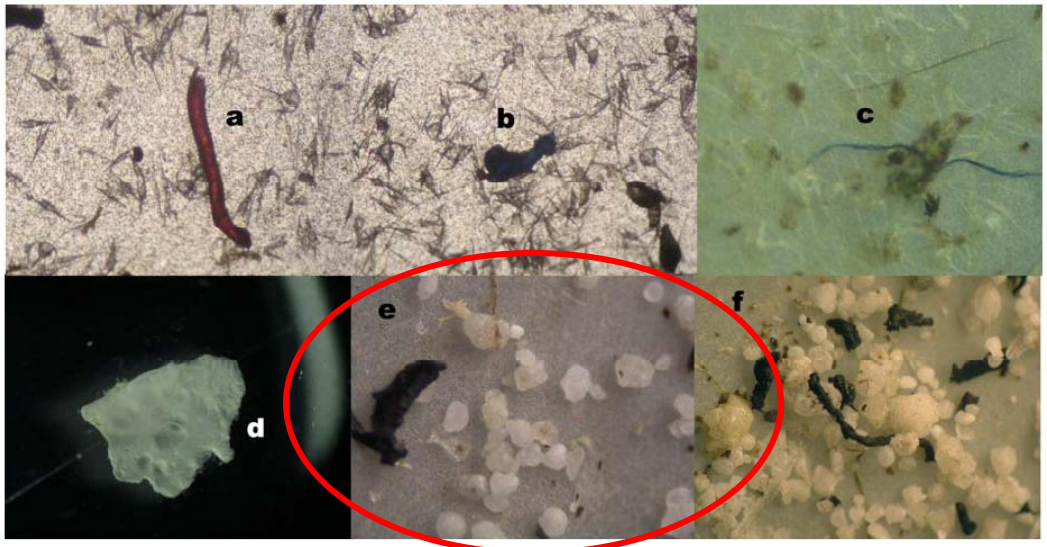
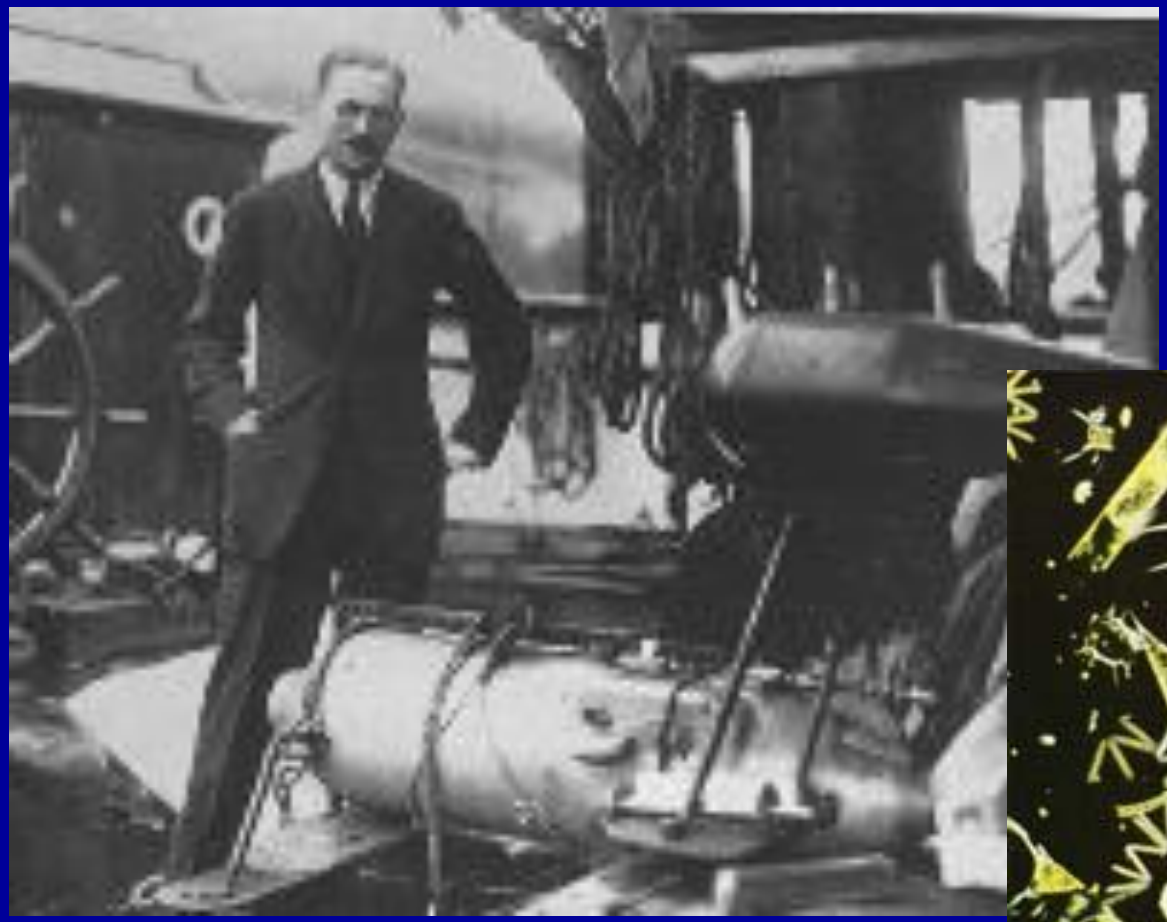


Figure 2 Different plastic particle in the water. A. Red plastic fibres (diam. ~70µm) B. Blue plastic particle C. Blue plastic fibre (diam~100µm) D. White/transparent plastic film, 1*1,5cm E. Milky-white plastic spheres, diam. ~0,4-2mm F. Milky-white plastic spheres and suspected tar particles.

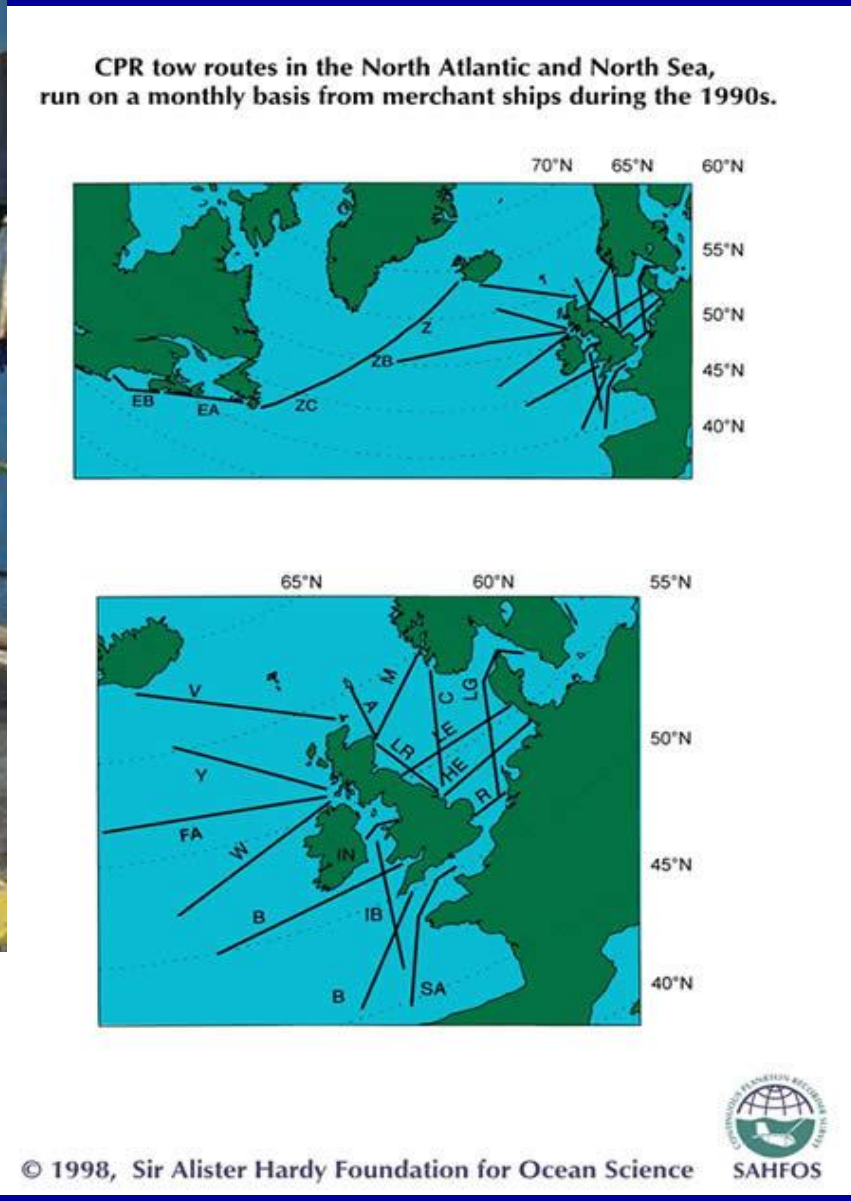
Not confirmed with FT-IR

Is microplastic accumulating ?



Sir Alister Hardy (1896 - 1985)

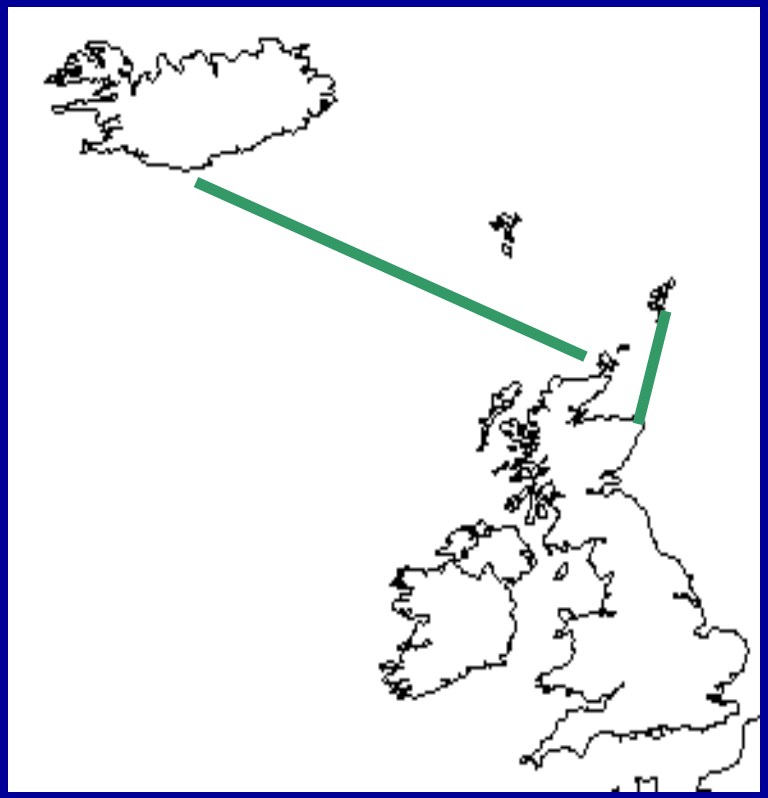
Temporal trends - from SAHFOS plankton samples

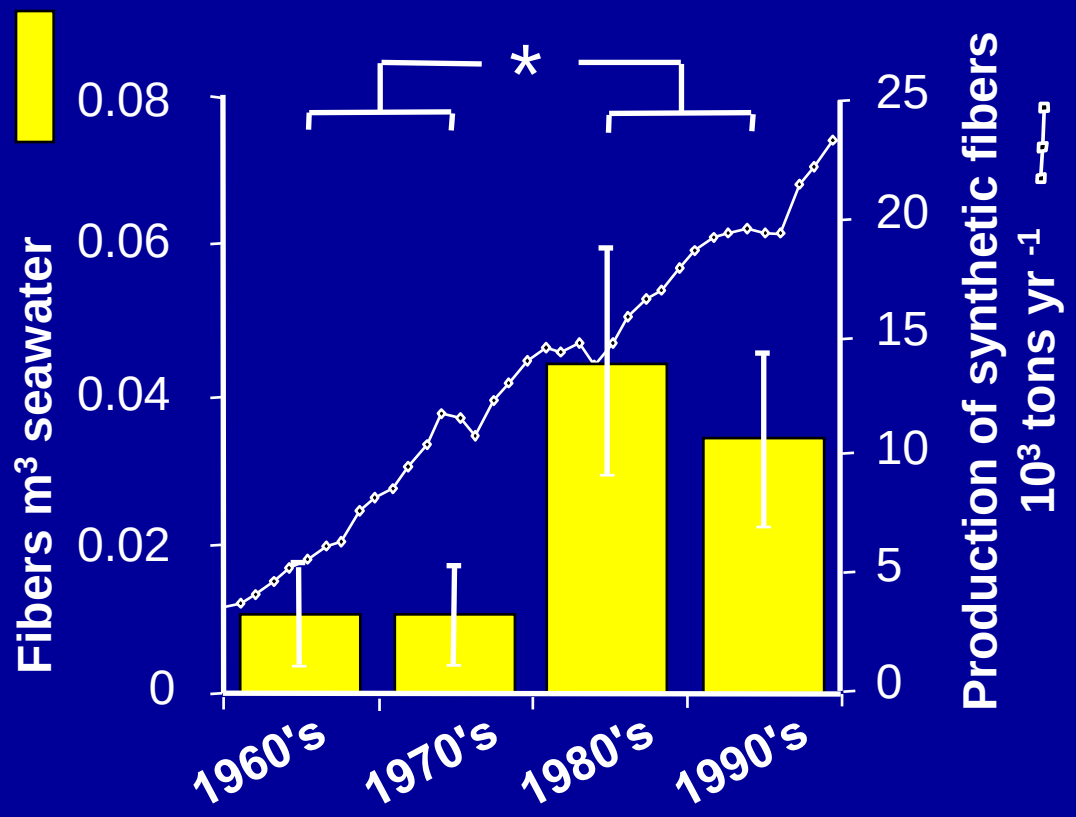


50 years of data, regular routes

Samples at 10m below surface

Temporal trends - from SAHFOS plankton samples





Significant increase over time

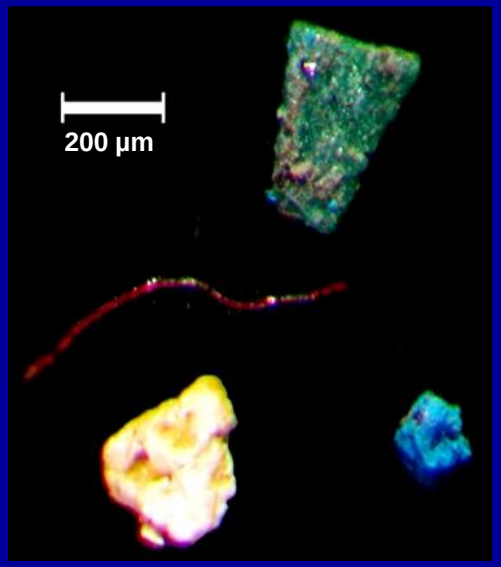
Less plastic on oceanic route

Thompson *et al.* 2004 *Science* **304**, 838

Conclusions 1

1. Microplastic widespread in oceans
2. Quantities variable - low , moderate, and high
3. Quantities increasing
4. Need to establish sinks
5. Best data we have is likely an underestimate
6. Need better methods to quantify

Potential sources of microplastic



Fragmentation of larger items
indirect introduction of particles

Sewage, sewage sludge
5 fragments g^{-1} Zubris & Richards 2005,
also Habib *et al.* 1995

Sewage sludge disposal sites – unpublished data presented at meeting but deleted here
Browne et al unpublished

Potential sources of microplastic

‘Biodegradables ?’ (photos from suppliers web site)

(EN 13432, ASTM D6400-99) = pre shredded plastic degrades in commercial composting plant in 180 days, 56 – 71 ºC, 50-60% humidity, aerobic, pH 7-8

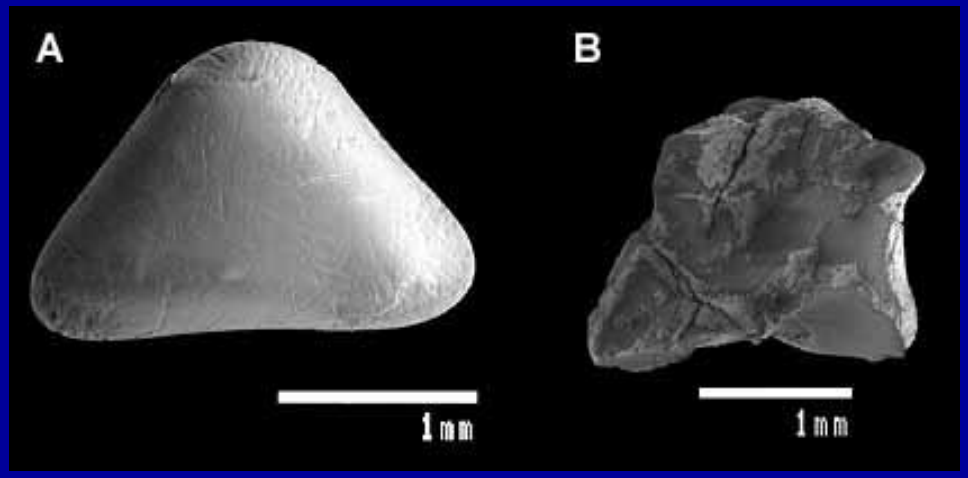
Sea trial of biodegradable bags Plymouth 2008

Potential sources of microplastic

Shredding and grinding by marine organisms

Bite marks in plastic bag made by amphipods

Braybrook & Thompson unpublished



Small fragments of larger items (worn and abraded) recovered from fur-seal excreta in Southern Ocean

Eriksson and Burton 2004

Potential sources of microplastic

Direct release of small particles

Plastic scrubbers - replacing natural abrasives in cleansing products

Plastic abrasives – for shot / media blasting boats, aircraft

Raw materials - for plastic production e.g. Roto-moulding

Is microplastic a problem?

1) If ingested microplastic could present a physical hazard?

2) If ingested microplastic could present a chemical hazard?

a) Plastics sorb hydrophobic pollutants - could desorb when ingested? (e.g. Mato *et al.* 2001, Teuten et al. 2007)

b) Chemicals used in manufacture could be released from plastics ?

Microplastic is ingested

Filter feeder

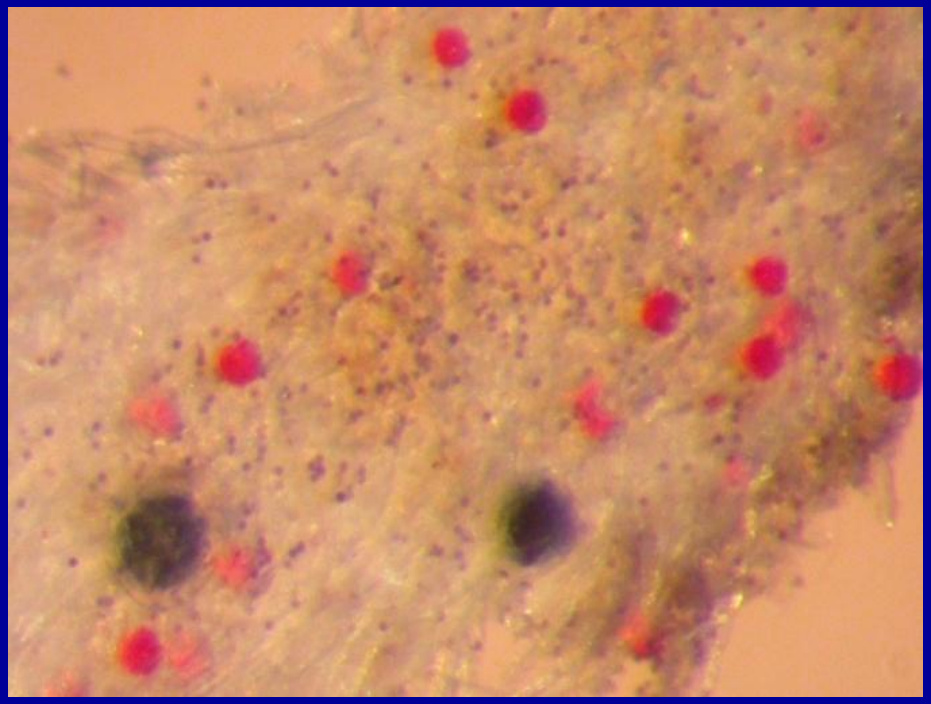
Semibalanus balanoides

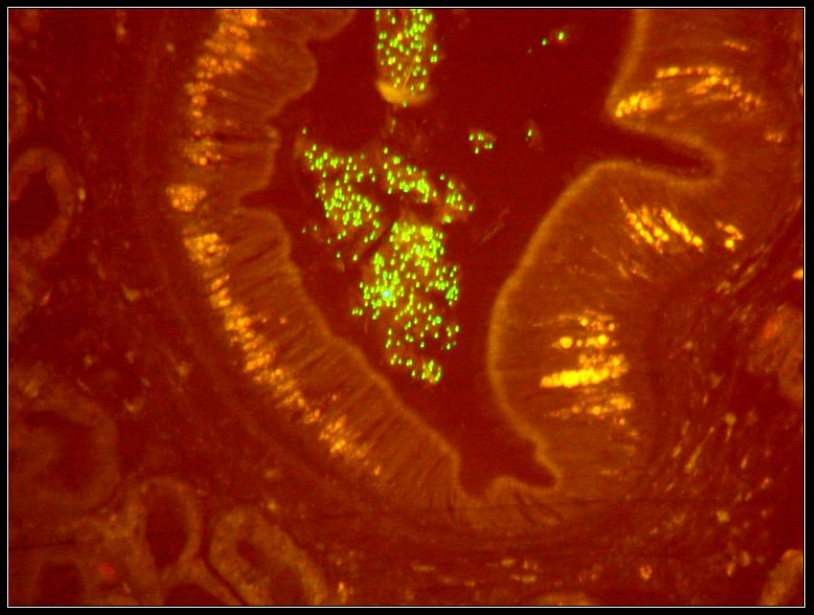
Deposit feeder

Arenicola marina

Detritivore *Orchestia gamarellus*

Microplastic is ingested





2 µm microplastic in gut cavity of *M. edulis*

Some defecated within days

Some retained for weeks

Some evidence of selectivity influencing size and abundance of material ingested

Browne et al. 2008

Concentrations of organic contaminants either sorbed to plastic debris or incorporated during manufacture

Chemical	Sources	Environmental concentration	Toxicity	**LC50** in aquatic invertebrates
Nonylphenol log K_{ow} = 5.8 [41]	Alkyl phenols present as degradation products of detergents and of polymer antioxidants [see 11] present as stabilising additive in some plastics	up to 10.0 µg g^{-1} on floating plastic [11]	irritant, potential reproductive toxicant; oestrogen mimic [42]	17- 3,000 µg L^{-1} [invertebrates and fish 43]
Phenanthrene log K_{ow} = 4.6 [44]	Polycyclic aromatic hydrocarbon present as a product of numerous combustion processes [45]	up to 1.1 µg g^{-1} for PAHs on floating plastic [12]	carcinogen [46] and immunotoxin [47]	51-57µg L^{-1} [polychaete sp. 48]
Triclosan log K_{ow} = 4.8 [49]	chlorinated diphenylether, present as antimicrobial agent in some plastics	Added to plastics (0.1 to 5% by mass) as an antimicrobial agent	cytotoxic in vitro [51]	260-370 µg L^{-1} [Daphnia sp 52]
TBDE log K_{ow} = 6.2 [53]	Brominated diphenyl ether, present as flame retardant in some plastics	Added to plastics (5 to 30% by mass) as a flame retardant [	hepatoxic, thyroid disruptor, neuro-developmental toxicant [see 37]	360 µg L^{-1} [Daphnia sp. 54]

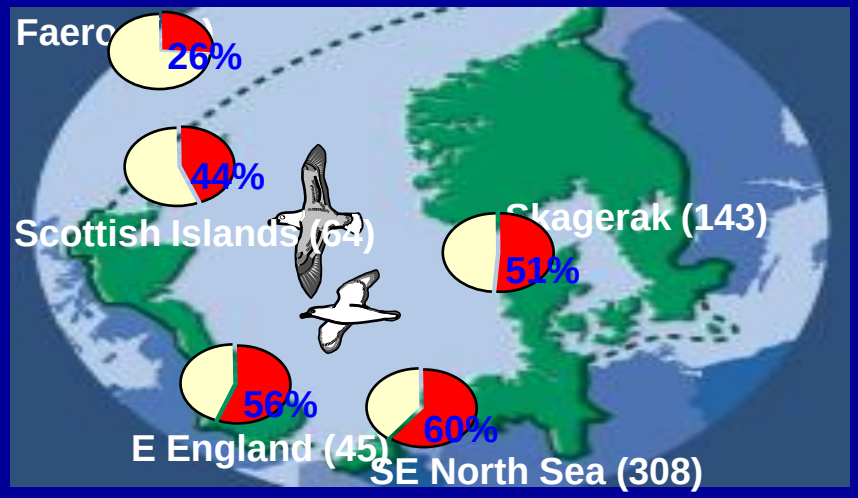
SAND
Phase 4
5E
4E
2D
7D
4C
3C
2000 mL
PYREX

This slide showed unpublished data on uptake of contaminates from plastics by a deposit feeding invertebrate (Thompson et al. Unpublished data)

Wider implications of chemical transport

Not just a concern for microiplastic 160 species known to eat plastic (mammals, birds, fish, reptiles)

stomach contents of Minke whale



PCBs in seabirds correlated with plastic ingestion

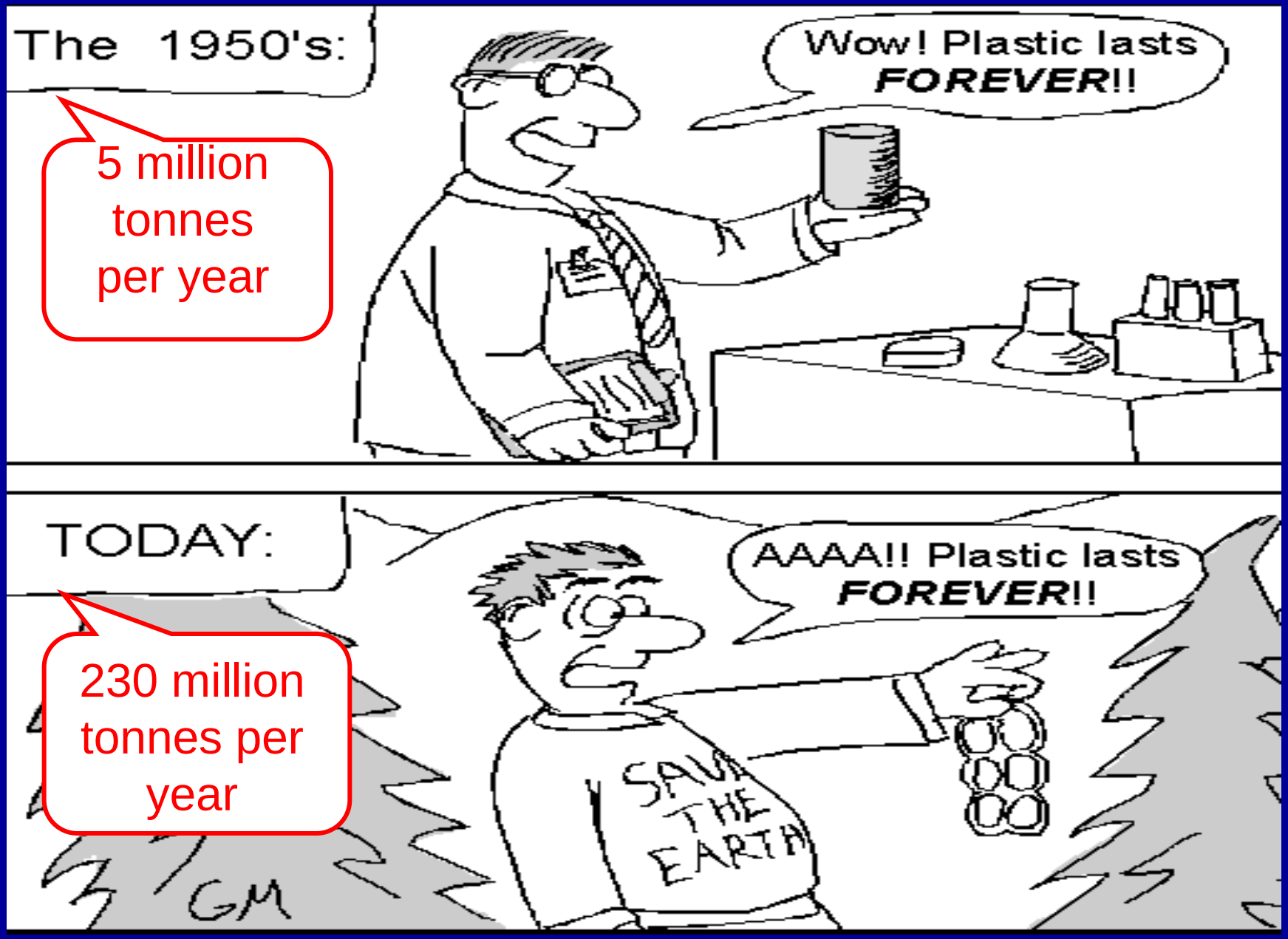
Conclusions 2

- Creatures ingest and some retain microplastics
- Microplastics likely to transport chemicals to organism
- Small particles probably have greater potential for transport to a wider range of organisms

Microplastics - research Priorities

- Sources: direct (abrasives and powders) & indirect (fragmentation and biodegradables)
- Sinks: habitat type and associated organisms
- Quantities of plastic ingested by organisms
- Establish environmental relevance of plastic debris in the transport of chemicals - context specific (habitat / organisms / plastic type / contaminant type)

Bigger picture



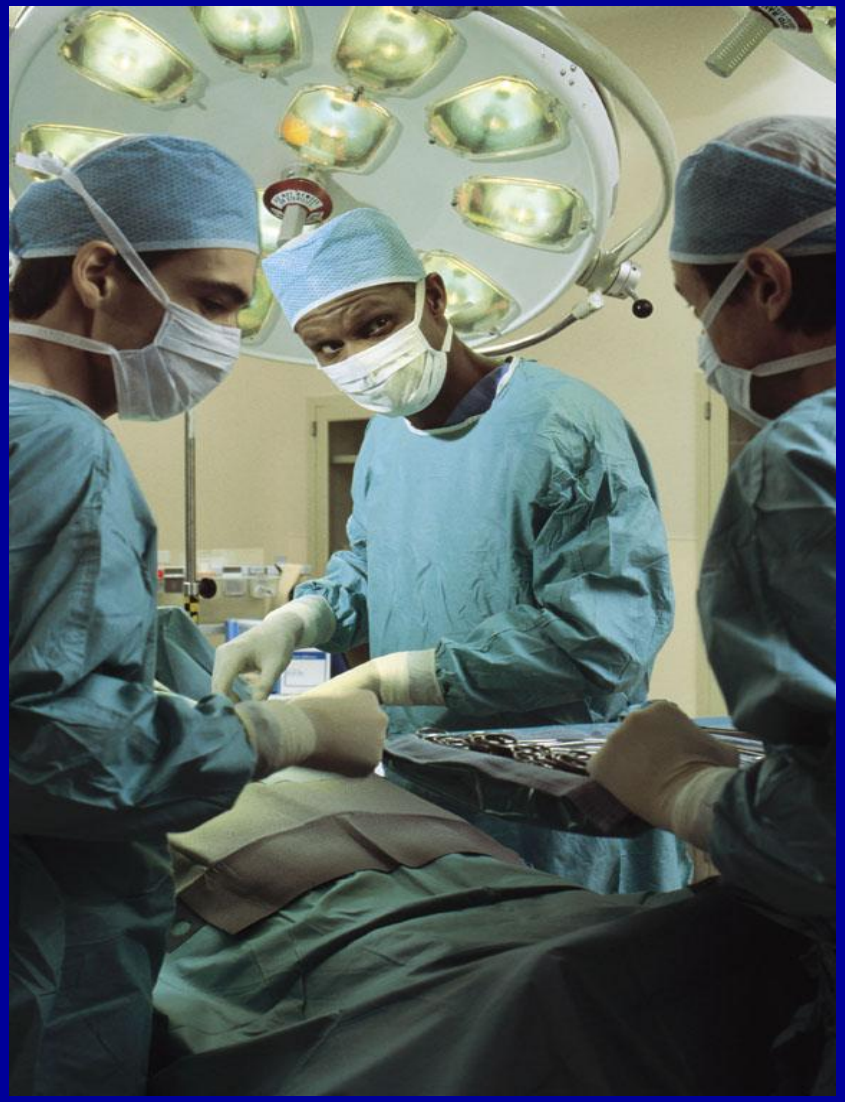
Benefits of plastics

- Light weight
- Versatile
- Inexpensive
- Durable

Uses of plastics

Automobiles = 7% of plastic used in EU

Uses of plastics



Uses of plastics

Disposable packaging = 37% of plastic used in EU

Packaging lifespan < 1 year

Where does it all go?

Most plastic rubbish goes to landfill

Where does it all go?

Some is dumped and now litters the environment

Conventional plastic remains in the environment

‘All of the plastic that has ever been produced remains as molecules too large for biodegradation’

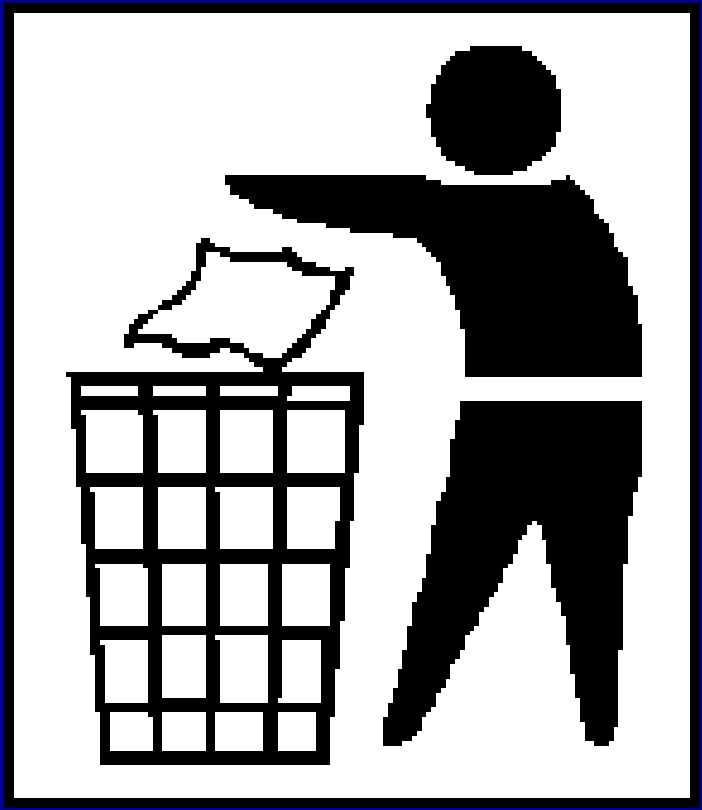
Andrady, 2003

100 years ?

1000 years ?

10000 years ?

What can we all do ?



Dispose of plastic properly

Marine: Legislation and appropriate facilities at ports

8% of world oil production used to produce plastics

Not sustainable

What can be done collectively ?

‘Difficult to recycle mixed plastics’

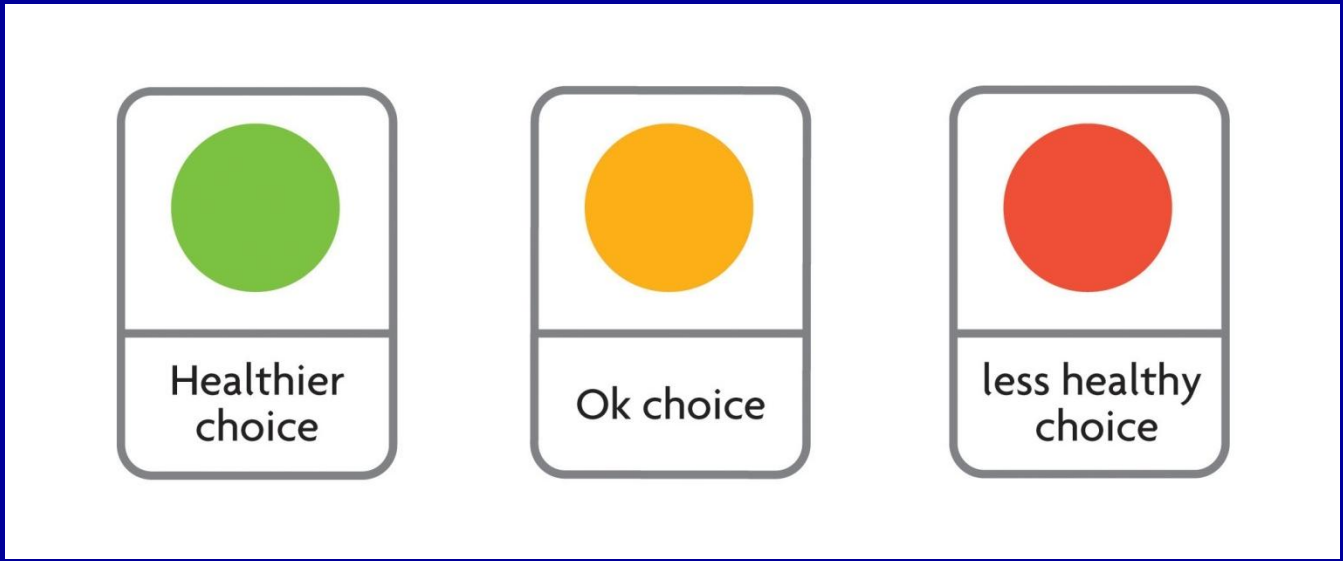
Problems ?

‘Difficult for consumers to separate polymers’

What government agencies could do to help ?

Set standards for packaging, recyclability, and degradability

give guidelines to consumers



e.g. the traffic light scheme used by food standards agency

What can be done?

No single solution - combination of actions required

- Dispose of plastic properly
- Reduce, Re-use, Recycle
- Appropriate use of biodegradable plastics
- Help clean- up
- Education

SESSION I: OCCURRENCE OF SMALL PLASTIC DEBRIS IN THE MARINE ENVIRONMENT

Fate of Plastics Debris in the Marine Environment

Dr. Anthony L. Andrady, Research Triangle Institute, Durham, NC, USA

Abstract: Certain classes of plastics, those used in the fabrication of fishing gear and those used in packaging applications are present in quantity in the marine environment. Most of these are non-biodegradable formulations of nylons and polyolefins that are used in netting and ropes. Expanded polystyrene from packaging and floats as well as polyolefins from consumer packaging materials are also commonly present.

The usual factors that facilitate the deterioration of these materials on exposure to land environments, mainly solar UV-B radiation and high temperatures have a limited impact floating plastics debris. This results in markedly retarded degradation of plastics in the oceans. Mineralization of these and their return to the carbon cycle must therefore be a very slow process. The plastic microparticles well known to be present in the oceans, likely originate from both the slow deterioration of the floating or submerged plastics, as well as the fragmentation of plastics degraded to embrittlement in the beach environment. Analysis of the collected particles cannot determine their origin but can only identify the chemical class of the plastic. Also, a significant fraction of the plastic fragments on beach and in water consists of virgin prils that mainly enter the environment during transport. These not being compounded will degrade at a relatively faster rate both on land and at sea.

This discussion will summarize the chemical aspects degradation of the relevant classes of plastics, review the criteria for degradation in these systems and discuss the chemistries for enhancement of plastics degradation. Special emphasis will be on the origins and the fate of polymer microparticles.

Tony Andrady, PhD, is a Senor Research Scientist at the Research Triangle Institute in North Carolina. He is a Material Scientist with a research interest in issues relating to plastics debris in the Marine Environment.

Fate of Plastics in the Oceans

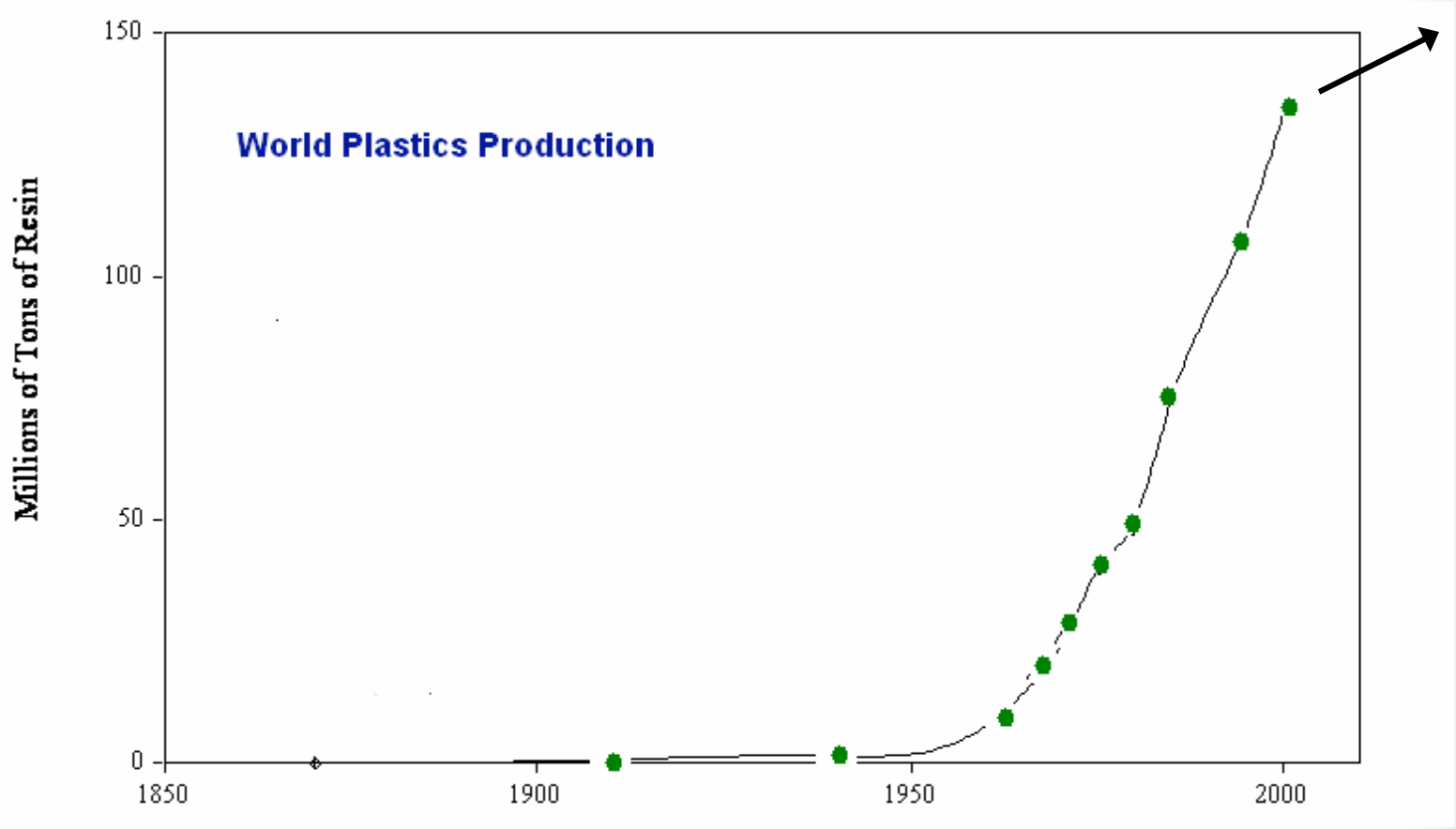
Anthony L. Andrady

September, 2008

turning knowledge into practice

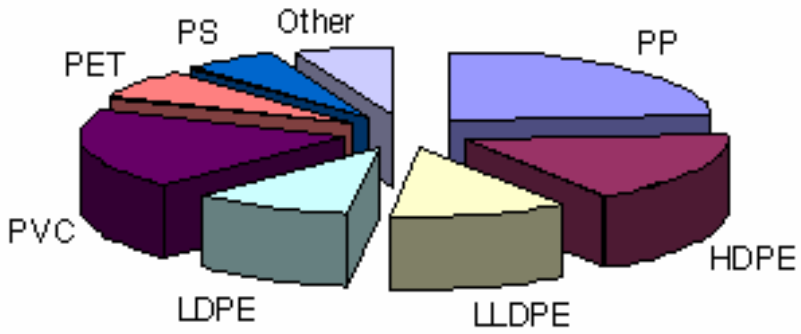
RTI International, Research Triangle Park, North Carolina

Global Resin Production



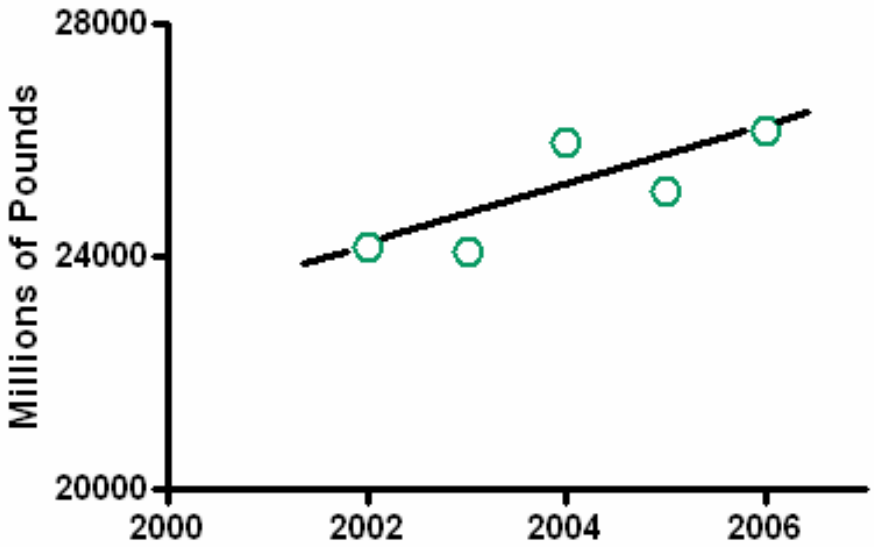
~140 mmt

Plastics Consumption Patterns - 2007



Plastic Type	Percentage
Polypropylene [PP]	24
Poly(vinyl chloride) [PVC]	19
Polyethylene – [HDPE]	17
Polyethylene – [LLDPE]	11
Polyethylene – [LDPE]	7
Polystyrene [PS]	6

Packaging Plastics Growth



Plastics Production in US: 113,202 million lbs [2006]

109,776 million lbs [2005]

About 30% of production worldwide is used in packaging applications.

Worldwide the trend is towards increased use of plastics in all applications.

Beach Plastics

~ 80% of plastics debris is via influx from beaches

Typical Product	Plastic Type	Origins
Resin Pellets	**Various** **PE, PP, PS** **PVC**	**Transportation losses** **Runoff from manufacturing processes**
Styrofoam pieces from floats, foam cups, boxes and packaging fill material.	**PS (foam)**	**Fragments of foam (possibly from cups, bait boxes, fast food containers, and buoys (foam).**
Compounded plastic fragments	**Various**	**Caps and lids,** drinking straws**, bags and wrappers,** **cigarette lighters, trash bags, toys, buckets, milkjugs,** **water** bottles**, 6-pack holders, plates, meat trays, oil** **and lube bottles, lures and floats, light sticks**
Cigarette filter	**CA**	**Beach litter**
Fishing-related Debris	**PE,PP, PA, PS**	**Fishing line,** net fragments**, bait box fragments,** rope**, strapping bands,** floats buoys
Personal Hygiene Products	**LDPE, PP**	**Tampon applicators, condoms, diaper fragments, syringes**

Density of Common Plastics

- **Gear-related plastics**
  - **polyethylene [0.92-0.97]**
  - **polypropylene [0.91]**
  - **nylon [1.14]**
  - **polyester [1.38]**

- **Packaging-related plastics**
  - **polyethylene, polypropylene**
  - **PVC [1.38-1.41]**
  - **polyester**
  - **polystyrene (styrofoam) [<0.2]**

Density of Sea Water {T, Salinity, pressure} ~ **1.025**

However, most plastics are 'compounded' with additives. This changes the density.

What is quantified or described is the fraction with a density < 1.025.

What is Degradation?

DEGRADATION

- Photodegradation [Beach, Surface Water] — Solar UV-induced
- Thermooxidative Degradation [Beach, Surface Water] — Thermal oxidation
- Biodegradation [Surface Water, Deep] — Mediated by microorganisms
- Hydrolysis — Reaction with water

Of these only **photodegradation** (including photoinitiated oxidation) and **thermooxidation** takes place to any significant extent for plastics exposed to the marine environment. Biodegradation is too slow a process to be significant.

Degradation *vs* Deterioration

Deterioration: Reduction in particle size of the plastic due to a physical process

Degradation : When the plastic material undergoes chemical changes usually with a reduction in molecular weight

	Scission	No Scission
Main Chain	Decreases	Unchanged or Increases
Side Chain	Unchanged	Unchanged

True Biodegradation

Both process can and do occur simultaneously in environmental exposure

Testing for Degradation

Test Method	Deterioration	**Degradation**	Comment
Tensile Tests	**Yes**	**Yes**	**Not directly correlated**
Weight Loss	**Yes**	**Yes**	**Not directly correlated**
Substrate Depletion	**Yes#**	**Yes**	**Semi-quantitative**
Microbial Growth	**No**	**Yes**	**Qualitative**
Gel Permeation Chromatography [GPC]	**No**	**Yes**	**Semi-quantitative**
Respirometry	**No**	**Yes**	**Semi-quantitative**

These tests measure very different aspects of the process.

Tensile testing – measures mechanical integrity

Weight loss – fragmentation or depletion of substrate

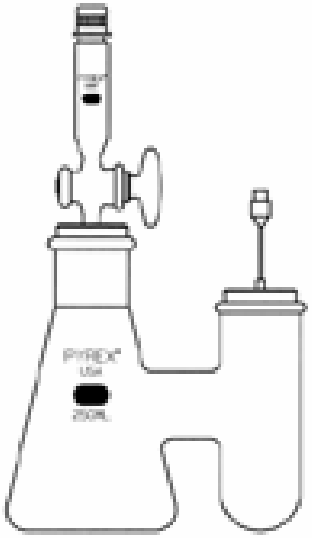
GPC – Chenge in molecular weight

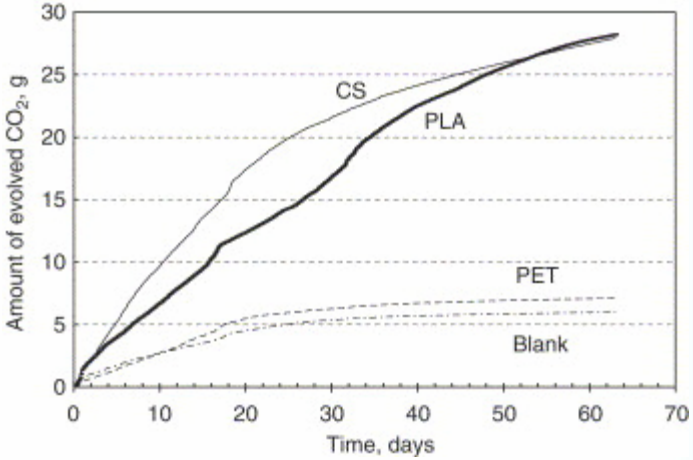
Respirometry – Conversion of carbon or mineralization

Mineralization

$$C_xH_y + \{(y+4x)/2\}\ O_2 \rightarrow x\ CO_2 + (y/2)\ H_2O$$

Titrimetrically Determined





Typical respitrometry data for biodegradation of polymers in soil

Respirometry provides a convenient means of quantifying biodegradation of plastics *in vitro*

Two Important Mechanisms

- **Degradation via Solar UV radiation**

  This can be due to photolysis of the polymer, but is more commonly due to photo-initiated oxidation of polymers.

  - **available to plastics less denser than sea water**

  (therefore, not available for nylons, polyesters, plastics in crab pots, weighted derelict gear.)

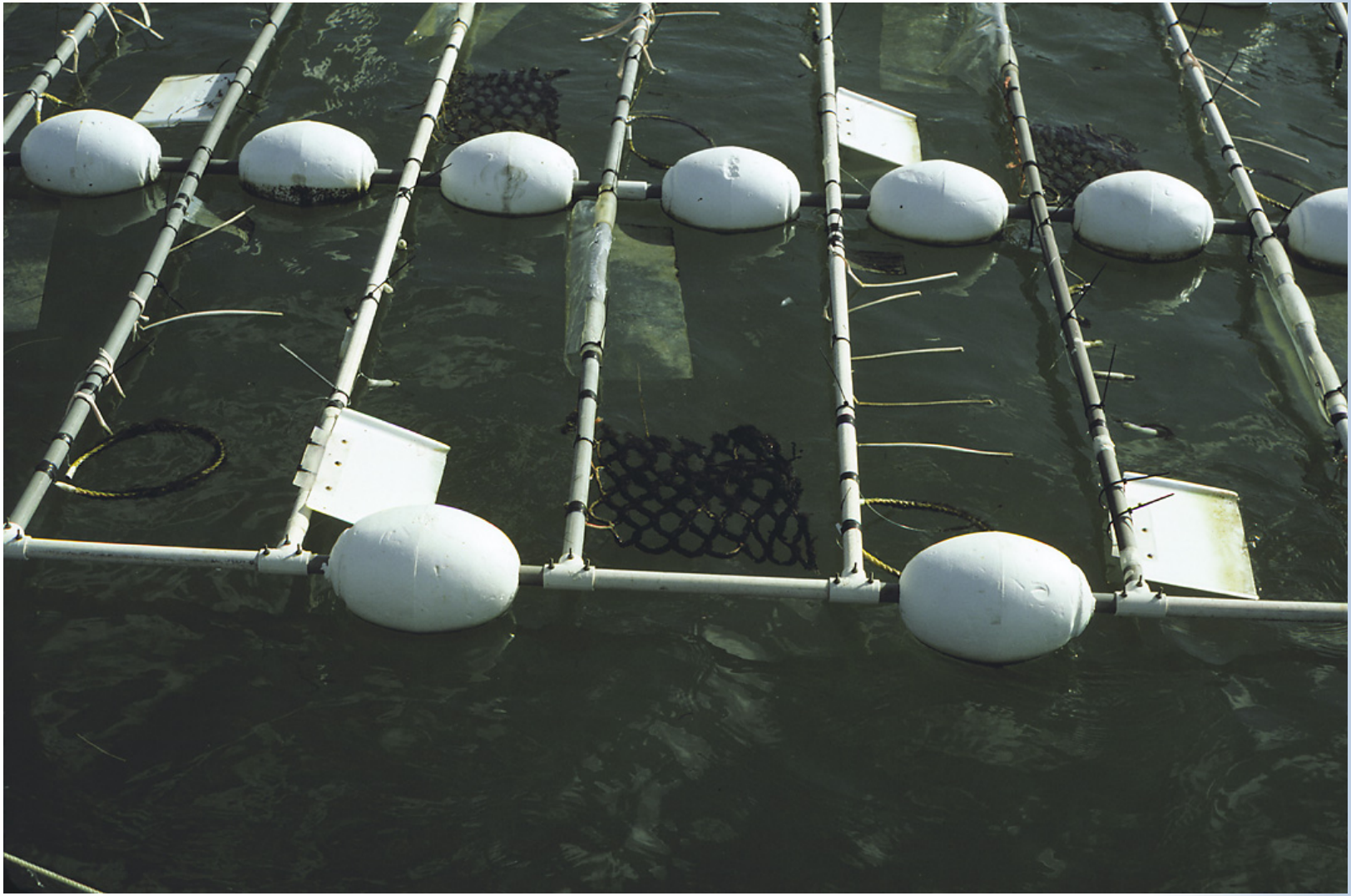
  - **available only prior to foulant coverage of the surface.**

- **Slow Thermal Oxidation**

  - **the rate of breakdown increases with ambient temperature.**

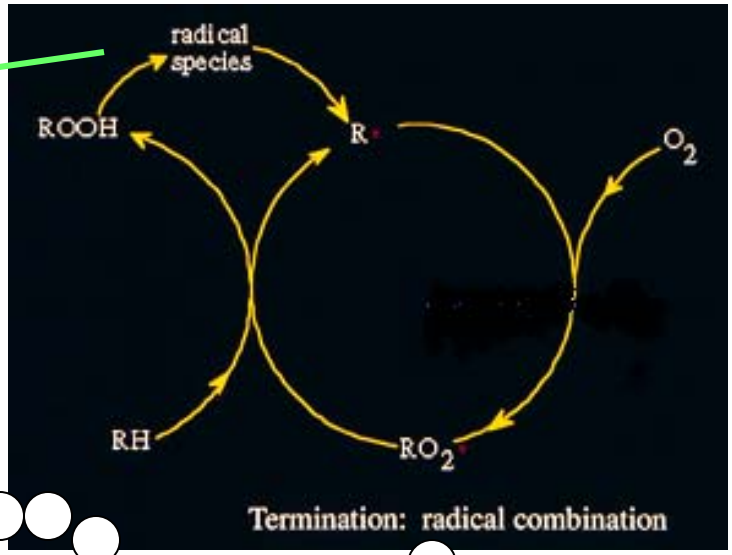
    (significant on land but greatly reduced rates at sea)

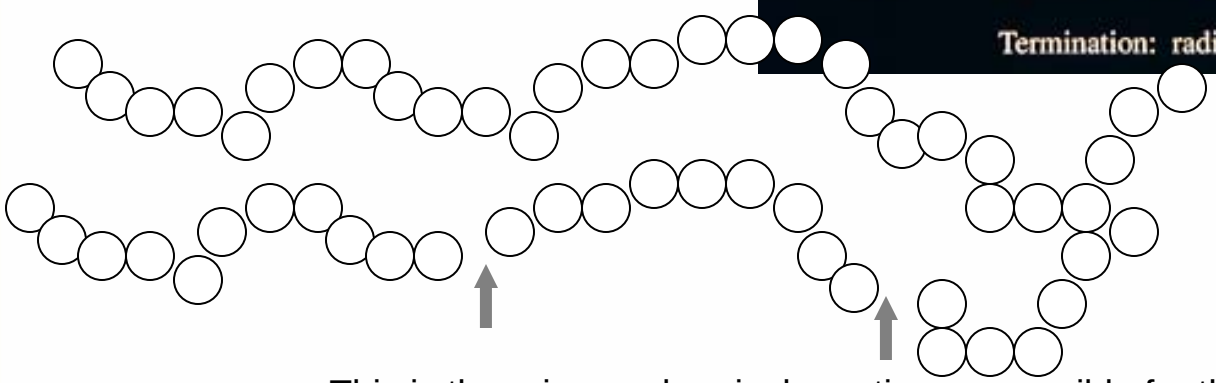
ASTM D5437-93 Exposure Method



Oxidative breakdown of Polyolefins

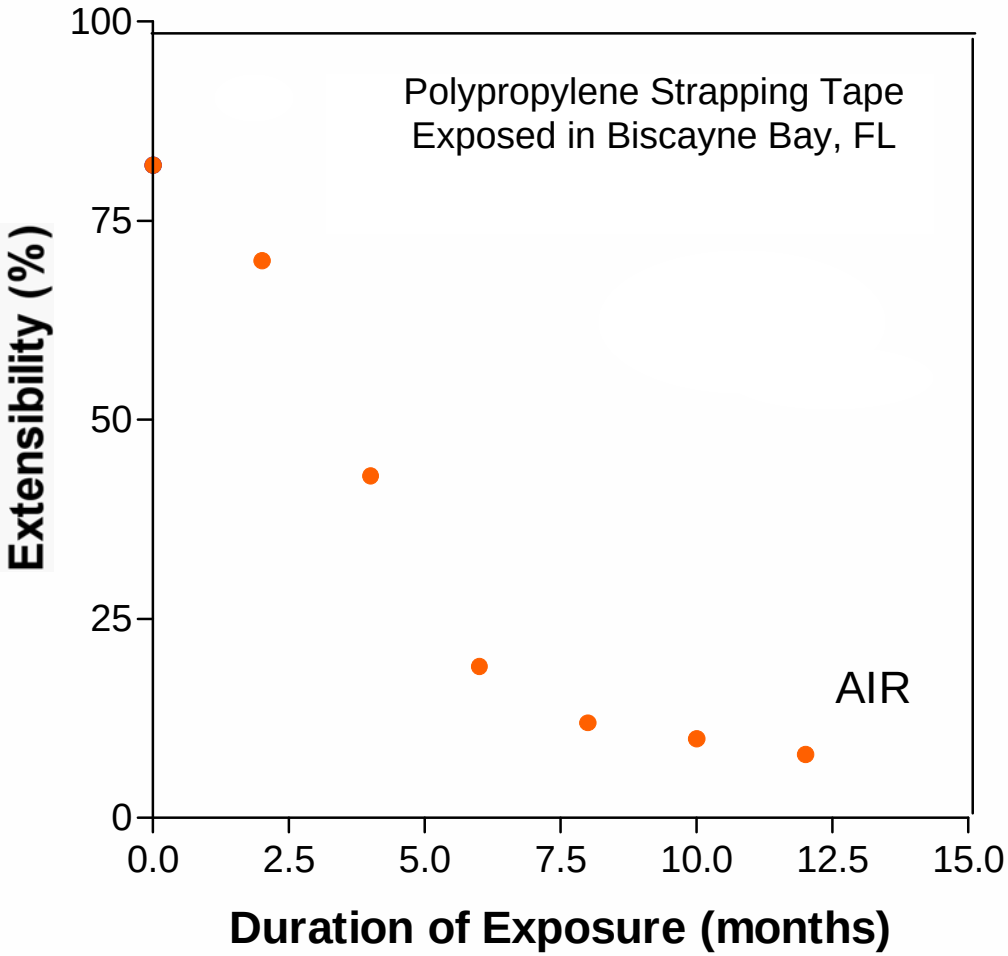
UV-Radiation facilitates this reaction





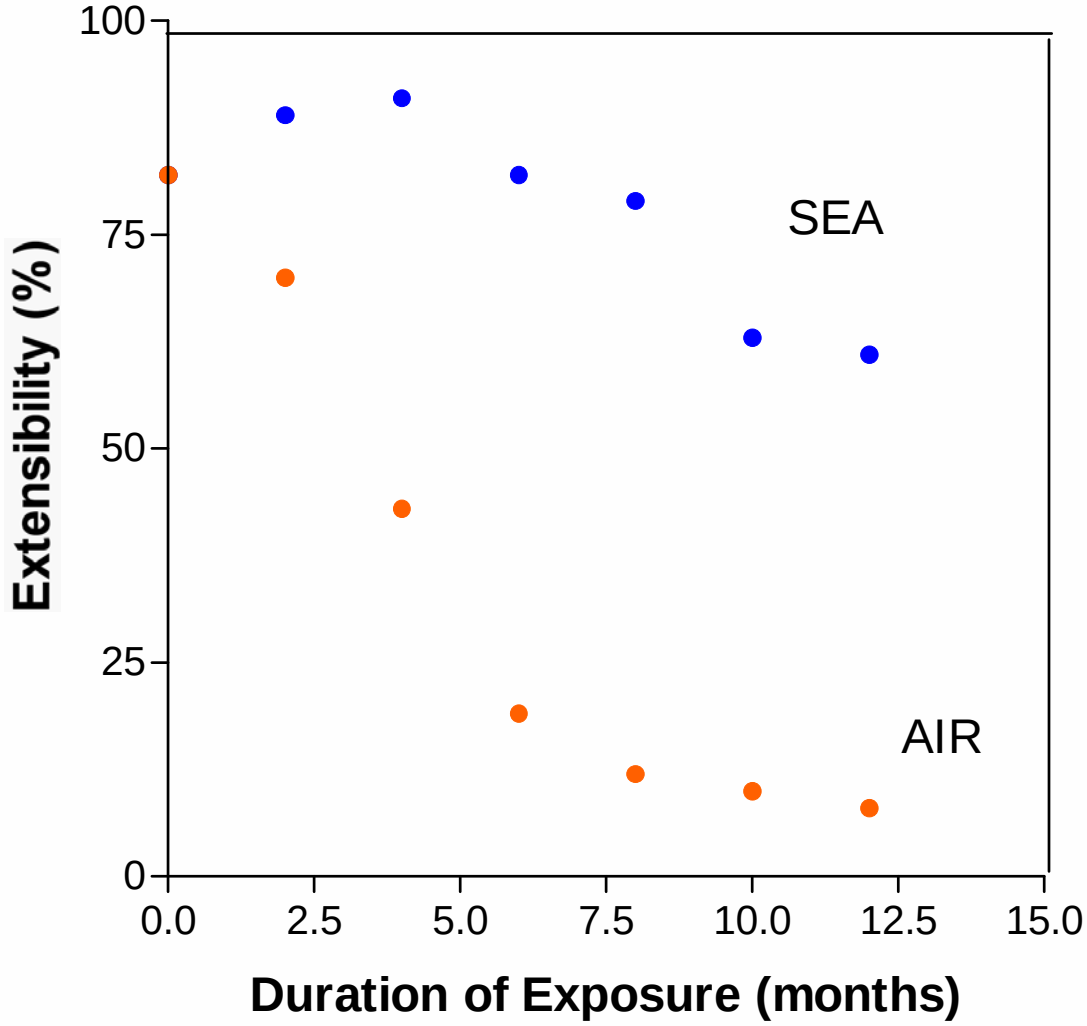
This is the primary chemical reaction responsible for the breakdown of polymers in the environment. Each cycle is associated with a scission event

Loss in Extensibility



Loss in extensibility is particularly sensitive to degradation of plastics. When extensibility reaches values of <5% the material is 'embrittled' or fragments on handling the sample. It is not even testable at this stage.

Surface-Water Exposure



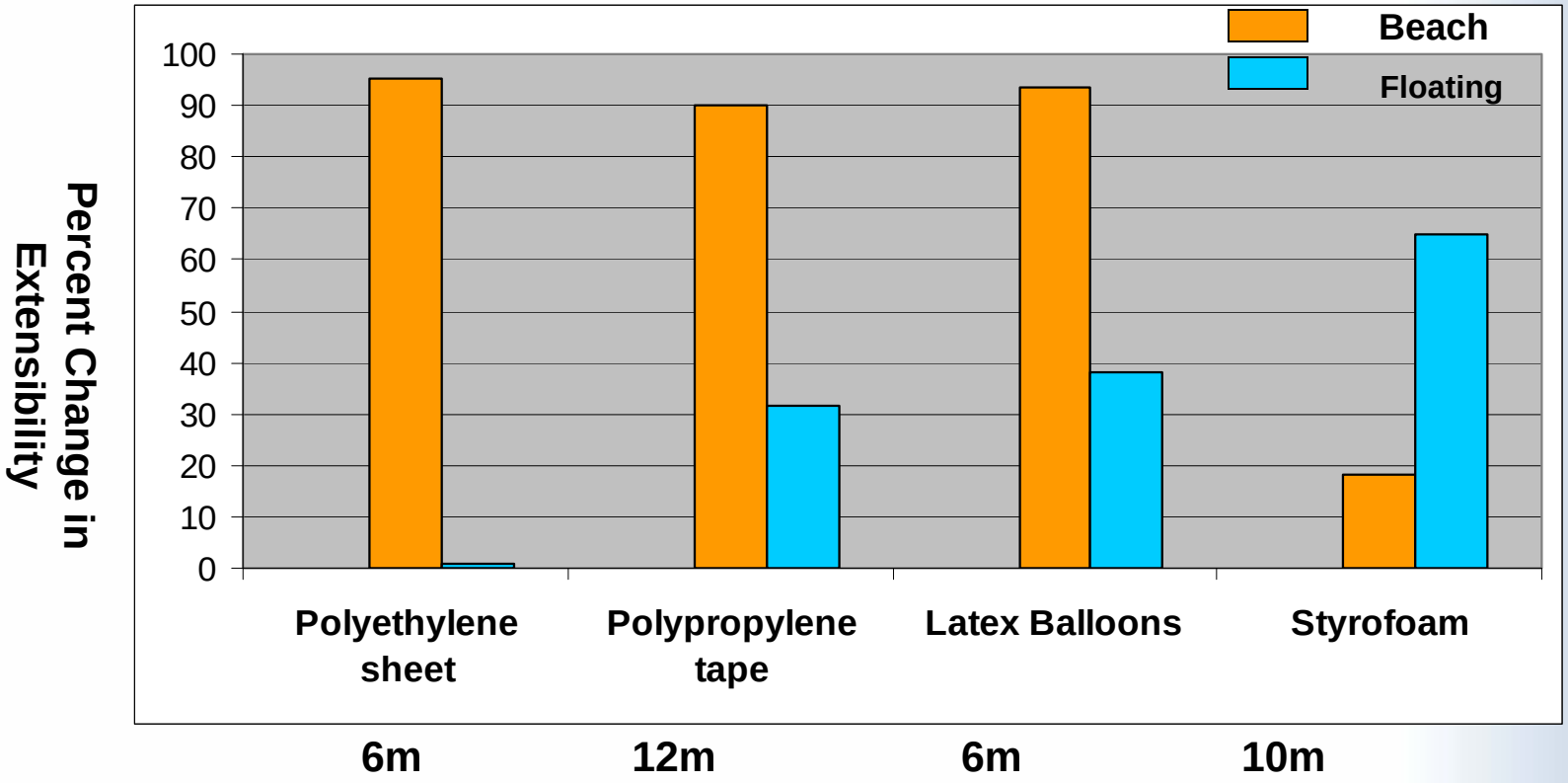
POLYPROYLENE

Strapping Tape

Biscayne Bay, FL

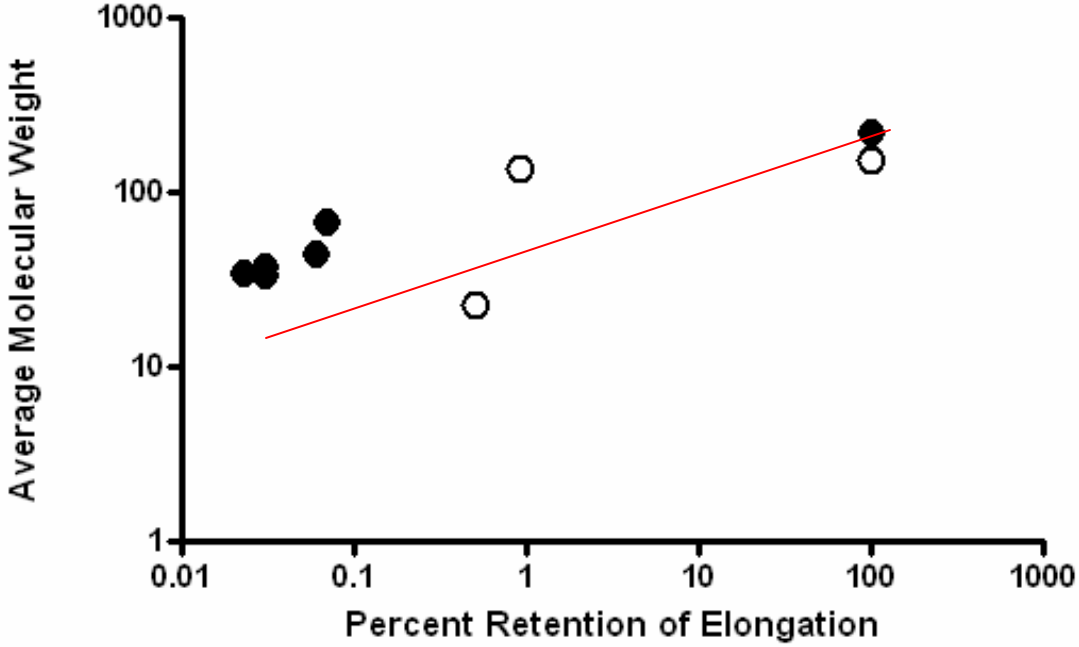
Marine exposure

Plastics Breakdown is slower at Sea



Except for Styrofoam other plastic materials breakdown much slower when exposed floating in sea water (both field studies and circulating sea water tank studies show this)

Is Embrittlement a Good Enough Endpoint?



Filled symbols: Andrady et.al. (1991): Open symbols Klemchuk et.al. (1984)

Plastics exposed to the point of embrittlement still have average molecular weight in the tens of thousands range. Molecules this large are not readily biodegradable.

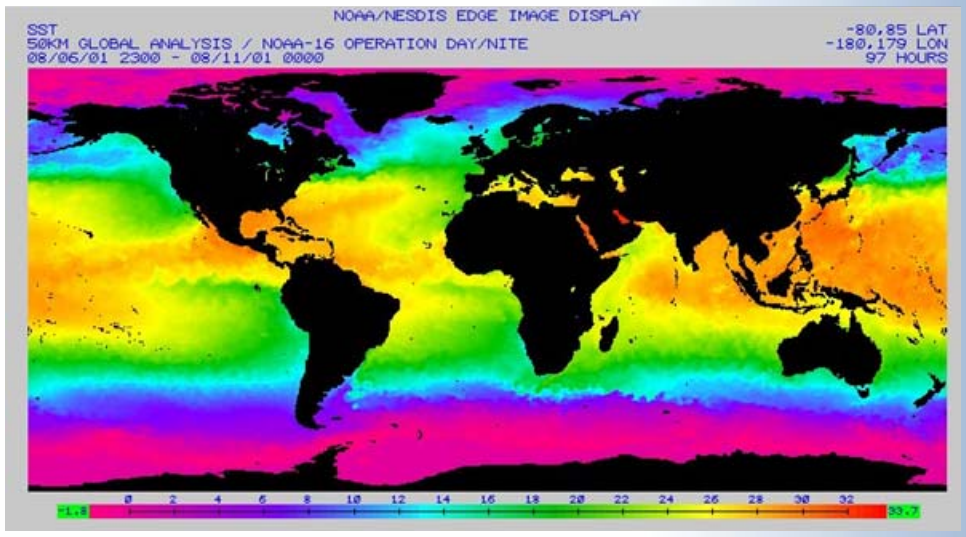
Why Slower at Sea?

Lower Temperature

Surface temperature at sea is ~ 20's ^{o}C. Plastics are oxidized at this temperature as ocean is a great heat sink.

Plastics on land heat up by absorption of IR to temperatures 10-40 ^{O}C higher than the ambient air temperature!

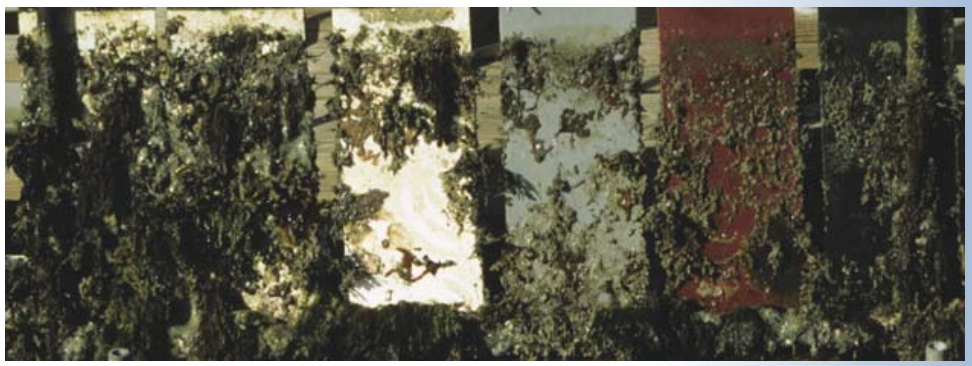
Arrhenius Equation applies!



FOULING

A second factor is surface fouling that shields the surface from exposure to sunlight.

Fouling of Plastic panels exposed submerged just below surface in Biscayne Bay. Floating plastics also undergo fouling.



Beach Environment – Nylon Netting

Breaking Strength (kgf) = 17.06 – 1.50(±0.11) * Duration (wks.) $r^2 = 0.96$

Tensile Extensibility (%) = 180.1 – 13.69 (±1.9) * Duration (wks.) $r^2 = 0.88$

Breaking Strength (kgf) = 16.55 - 1.29 (±0.15) * Duration (wks.) $r^2 = 0.91$

Tensile Extensibility (%) = 153.3 – 10.44 (±2.1) * Duration (wks.) $r^2 = 0.78$

Microparticle Origins

- Plastics debris on beaches undergo rapid and severe degradation. This may result in surface layer embrittlement that leads to the formation of microparticles. These are washed into the ocean.
- Plastics degrade much slower in sea water (floating exposure) compared to on beach or on land at the same location. This slow degradation can also lead to formation of microparticles in the ocean. However, it is reasonable to expect a relatively smaller contribution from this process.
- These plastic microparticles a) carry the constituents in the plastic from which these were derived; and b) can sorb and concentrate organic pollutants in the sea water.

The above explanation of the origin of microparticles is a reasonable hypothesis that is supported by indirect evidence at this stage.

The rate at which these microparticles are generated on beach exposures vary with the location and with the type of plastic material.

Microparticles

Debris Item

Deterioration and Degradation

Large Fragments

Deterioration and Degradation

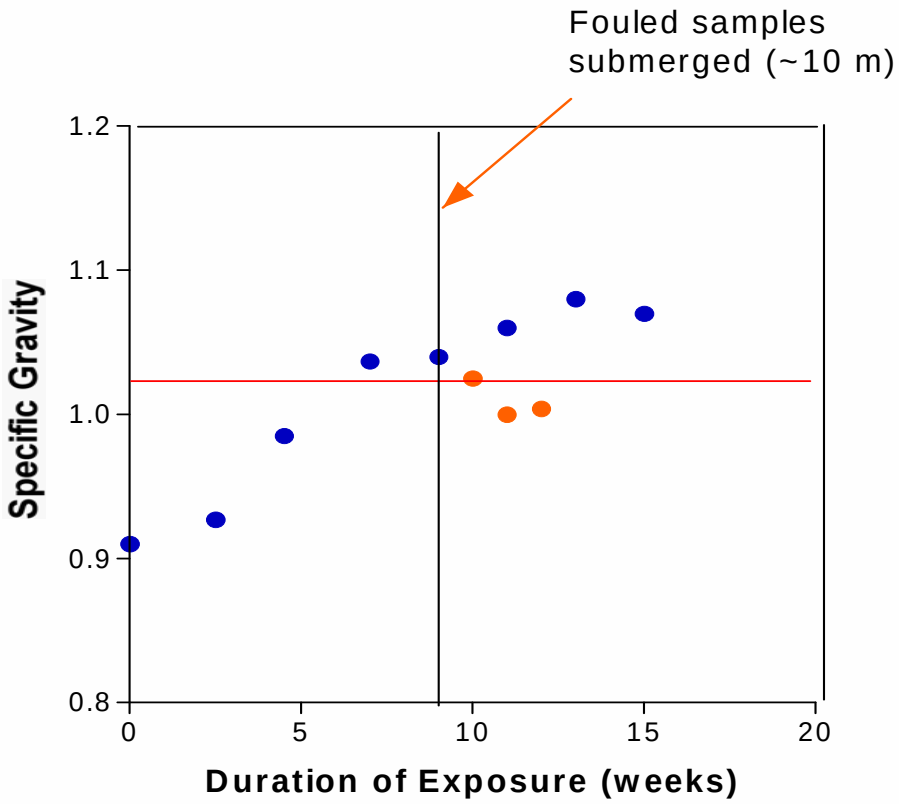
Surface degradation, flake off and attrition

Small Fragments

Microparticles

Density Changes with Fouling

Biscayne Bay, FL



Samples exposed floating in Biscayne Bay increased in density due to fouling. Fragments will sink to various depths as a result of fouling. Submerging a fouled sample below the photic zone alters the foulant community and decreases the density.

Do microplastics become negatively buoyant as a result of fouling? Is there a microparticulate transfer to benthic sediment? Are we undercounting the microparticles?

Possible Techniques for Microplastics

1. Neuston samples collect microplastics along with biomass and non-plastics debris. Plastics fraction needs to be isolated from this mix.

   - Using mineral acid digestion to remove cellulosic (biomass) fraction followed by gravimetric estimation.

   - Use a dye (rose bengal) that may selectively stain cellular material.

   - Use fluorescent spectroscopy to identify cells

2. Once the microplastics fraction is isolated it needs to be characterized.

   - Microscopy including optical and electron microscopy followed by imaging to get particle sizes

   - Light scattering studies to obtain size distribution.

   - Thermal analysis to identify plastic types. Spectroscopic identification based on characteristic peaks may also be possible.

   - Infra-red microscopy to identify individual microparticles.

3. Microparticles ingested by zooplankton.

   - Fluorescence spectroscopic techniques

Do Zooplanktons Ingest Microparticles?

No good quantitative data on ingestion.

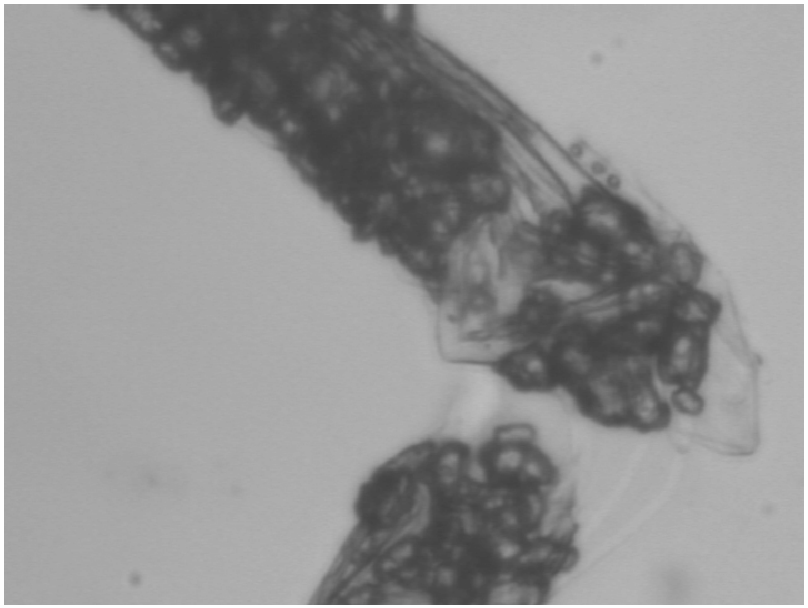
In this preliminary experiment the krill species *Euphasia pacifica* *was placed in water containing dispersed microparticles of polyethylene.*

- The zooplankton ingested the plastic microparticles freely.

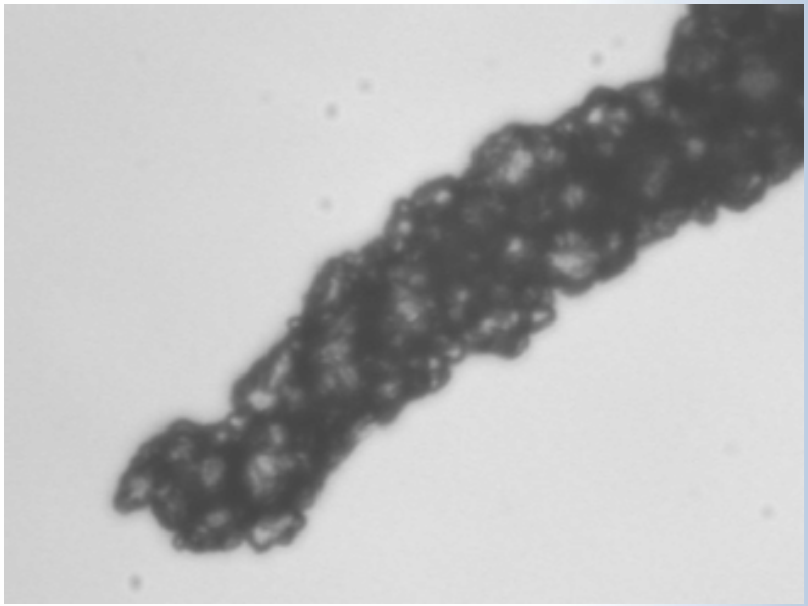
- When exposed to a mixture of the staple algae and microparticles both were ingested with little or no preference

Field study with Professor Alice Aldredge

Polyethylene Ingestion



Plastic Particles in gut



Plastic in Fecal Pellet

1. Average particle size = 20 microns
2. Fresh zooplankton sample tested in a container

What is Known

1. Nearly all the degradation of plastics in the marine environment is by photo-initiated oxidative degradation
2. Degradation rate is very much slower at sea than on land. This is particularly true for negatively buoyant plastics.
3. Microparticles can be generated by extensive light-induced degradation on beach and then transported into the sea.
4. These microparticles that result from embrittled product can be ingested by lower organisms and zooplanktons.

What is Not Known

1. At what rate will degradation of the small particles take place after embrittlement f the plastic material?
2. What fraction of microparticles are generated on beach and introduced to the sea (as opposed to produced at sea)?
3. What role do virgin plastic pellets play in microparticle generation?
4. Do microparticles also foul and sink in the water column? Are there microparticles in the benthos?
5. Is ingestion of small particles of plastics by zoo planktons and other invertebrates harmful to them? In what ways?
6. What is the bioavailability of the concentrated toxins to the feeder organisms? What are the transfer rates in key zooplanktons?
7. Is there a avoidance mechanism whereby the zooplanktons will not ingested microparticles that carry pollutants at high concentrations?
8. What are the food-web level implications of microparticles of plastics in the oceans?

Thanks and apologies for not being there!

Acknowledgements

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Microplastics as Accumulators and Sources of Persistent Organic Pollutants in Marine Food Webs: How Significant?

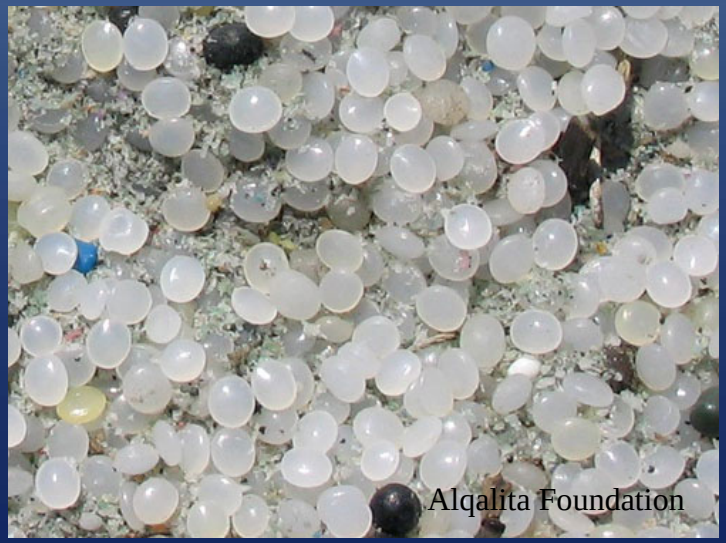
Dr. Alan J. Mearns, NOAA Office of Response & Restoration, Seattle, WA

Abstract: It has been nearly 40 years since Carpenter and Smith (1972) first reported the occurrence of plastic spherules in the Atlantic, including confirming the ability of Long Island Sound spherules to accumulate PCBs (Carpenter et al, 1972). Only recently have scientists again started exploring the role of microplastics as accumulators and vectors of Persistent Organic Pollutants (POPs). Microplastics accumulate POPs to part per million concentrations. However, there remain differences of opinion about the significance of microplastics as vectors of POP accumulation in marine wildlife. When birds or juvenile fish ingest microplasics, which is worse to the health of organisms and populations: the undigestible plastic or the POP's? Clearly, reducing microplastic inputs will reduce marine life injuries, regardless of the mode of injury. It remains unclear to what extent microplastics represent a source for food chain POP accumulation compared to other sources, such as marine organisms normal food. A risk assessment approach would help sort out the questions and their significance.

Alan J. Mearns, PhD, is an Ecologist and Senior Staff Scientist with the NOAA Office of Response and Restoration in Seattle, Washington. He holds a PhD in Fisheries from the University of Washington and Master's and Bachelor's degrees in Biology and Zoology from California State University in Long Beach. During the 1970's Alan was Leader of the Biology Division at the Southern California Coastal Water Research Project (SCCWRP) and in the 1980's Ecologist for the MESA Puget Sound Project and Leader of the National Status and Trends Historical Trend Assessment Program which evaluated longterm contaminant trends along the entire US coastline. Since 1989 he has been a member of the NOAA ERD (HazMat) Team supporting NOAA's Scientific Support Coordinators (SSC's) during oil spills and emergency response, including conducting longterm monitoring of recovery from the Exxon Valdez Oil Spill. He is also leader of the Water Environment Research Journal's Annual review of the Effects of Pollutants on Marine Life, which includes marine debris. He has been a science adviser to various national and regional committees involving bioremediation, wastewater discharges, cruise ship pollution, sediment bioassay methods, the San Francisco Estuary Institute (SFEI), the Coastal Response Research Center (CRRC) and is a member of the Science and Technical Committee of the Oil Spill Recovery Institute (OSRI) and EPA's Environmental Technology Verification (ETV) Program. During the past decade Alan has been using 3D trajectory models to support and facilitate consensus evaluation of the effects and benefits of alternative spill response options around the US and in Mexico and the Caribbean.

Dana Point, CA circa 1978

Microplastics as Accumulators and Sources of Persistent Organic Pollutants in Marine Food Webs: How Significant?



Alan J. Mearns
Senior Staff Scientist
Emergency Response Division

Office of Response and Restoration
National Oceanic and Atmospheric Administration
Seattle, Washington, USA

Observations

- PCBs in/on pellets range from 0.03 to 5 ppm dw (Carpenter, 1972, Rios et al 2007, Endo et al, 2005)
- "Bioconcentration" Factor for pellets from water is at least 100,000 to 1,000,000 (Mato et al, 2001)
- POP's can sorb/desorb, in water or sediments
- PCB's in shearwater tissue correlated with microplastic load (Ryan et al. 1988 (not in ref)

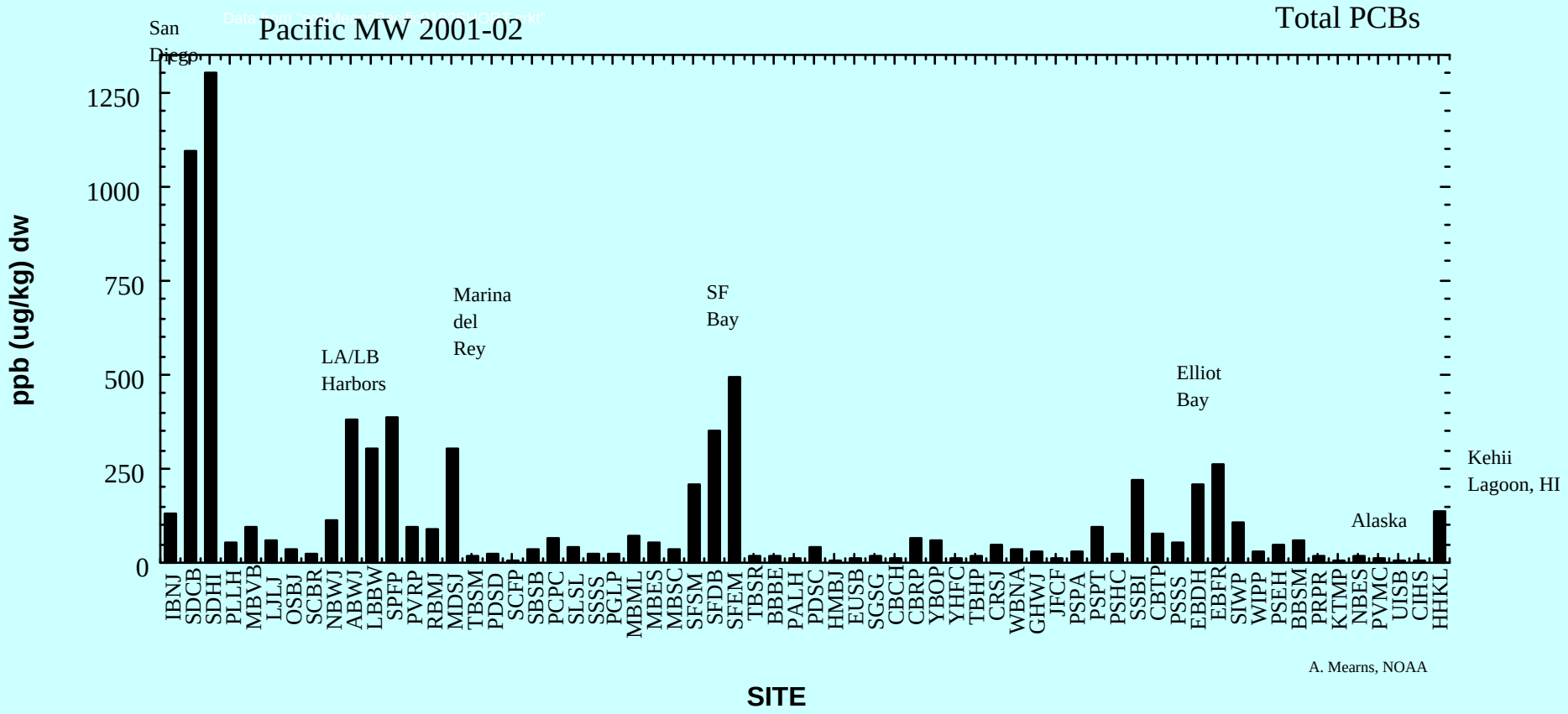
Thoughts

- Compare Apples and Oranges:
- Significance to marine and wildlife might depend on POP concentrations they experience from no-plastic food items
- So What are concentrations of POPs in marine prey, sediments, etc?

Nurdles

Mussels

Total PCB's in Mussels



PCB Comparisons

- Mussels US West Coast (Mearns,via Lauenstein):
  - Median 0.1 ppm dw
  - Maximum 1.3 ppm dw
- Regurgitated Pellets (Rios et al 2007)
  - Range 0.03 to 1.00 pm dw
- Atlantic open water pellets (Carpenter, 1972)
  - Mean? 5.0 ppm dw Aroclor
- Japan pellets (Endo et al 2005)
  - Range <0.03 to 2.3 ppm dw

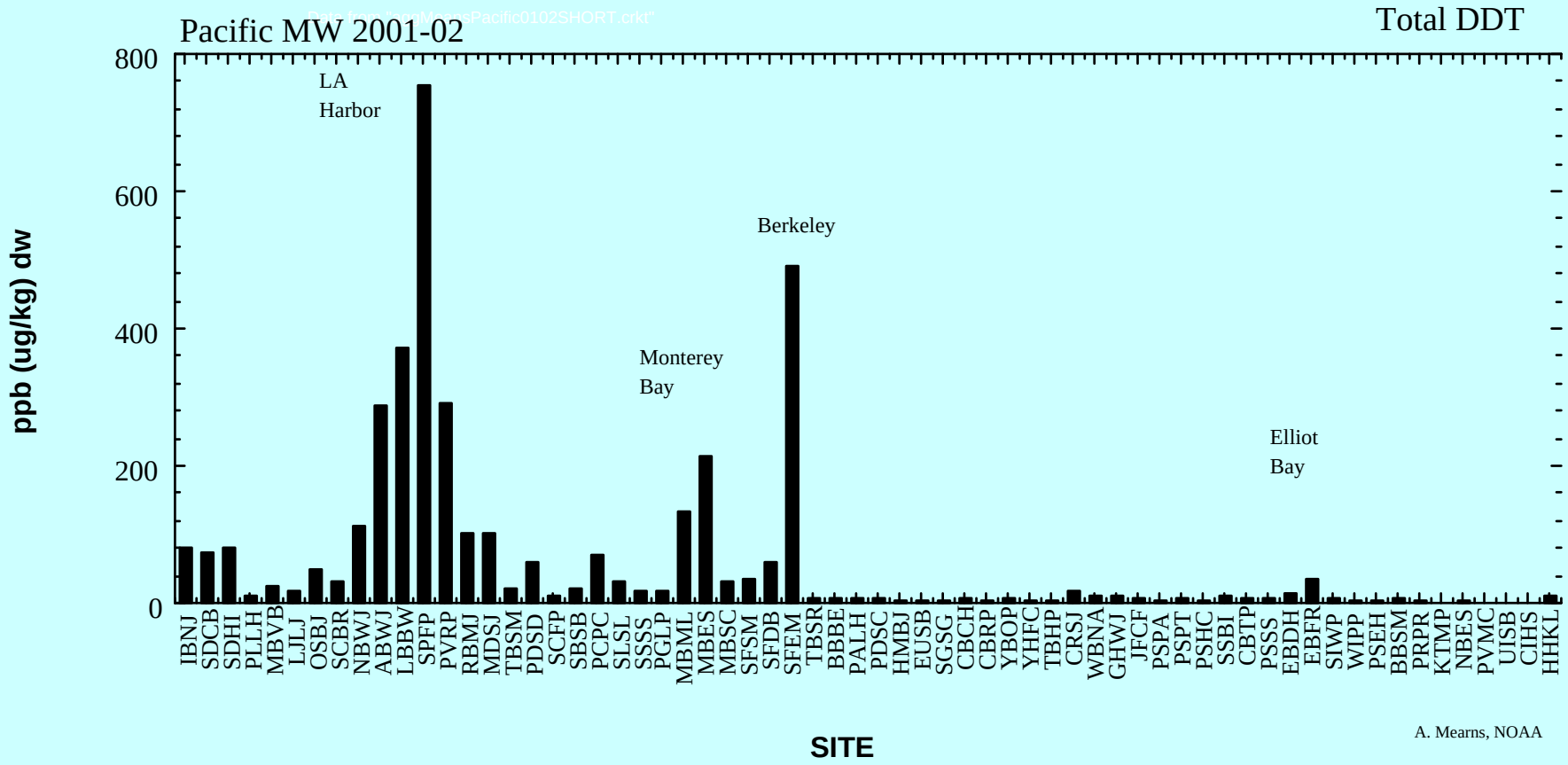
What about Other POPs?

- We got a lot of tissue data from marine organisms, including trends.
- POPs will be much higher at trophic levels higher than mussels (II)
- We need geographically comparable microplastic and biota POP data

What about other substrates?

- Sediments……
- Micro-micro plastics…plastic dust?

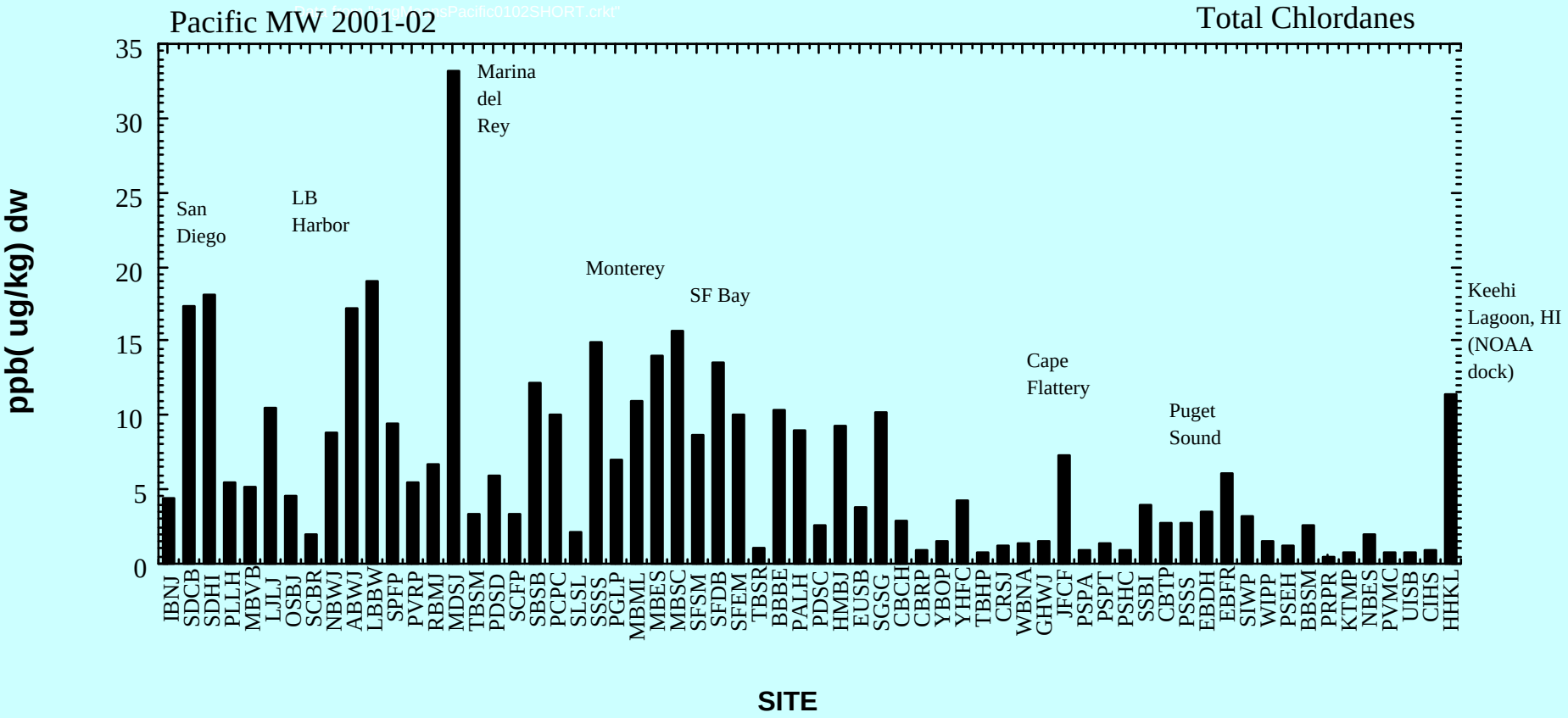
Total DDT in Mussels (ppb dw)



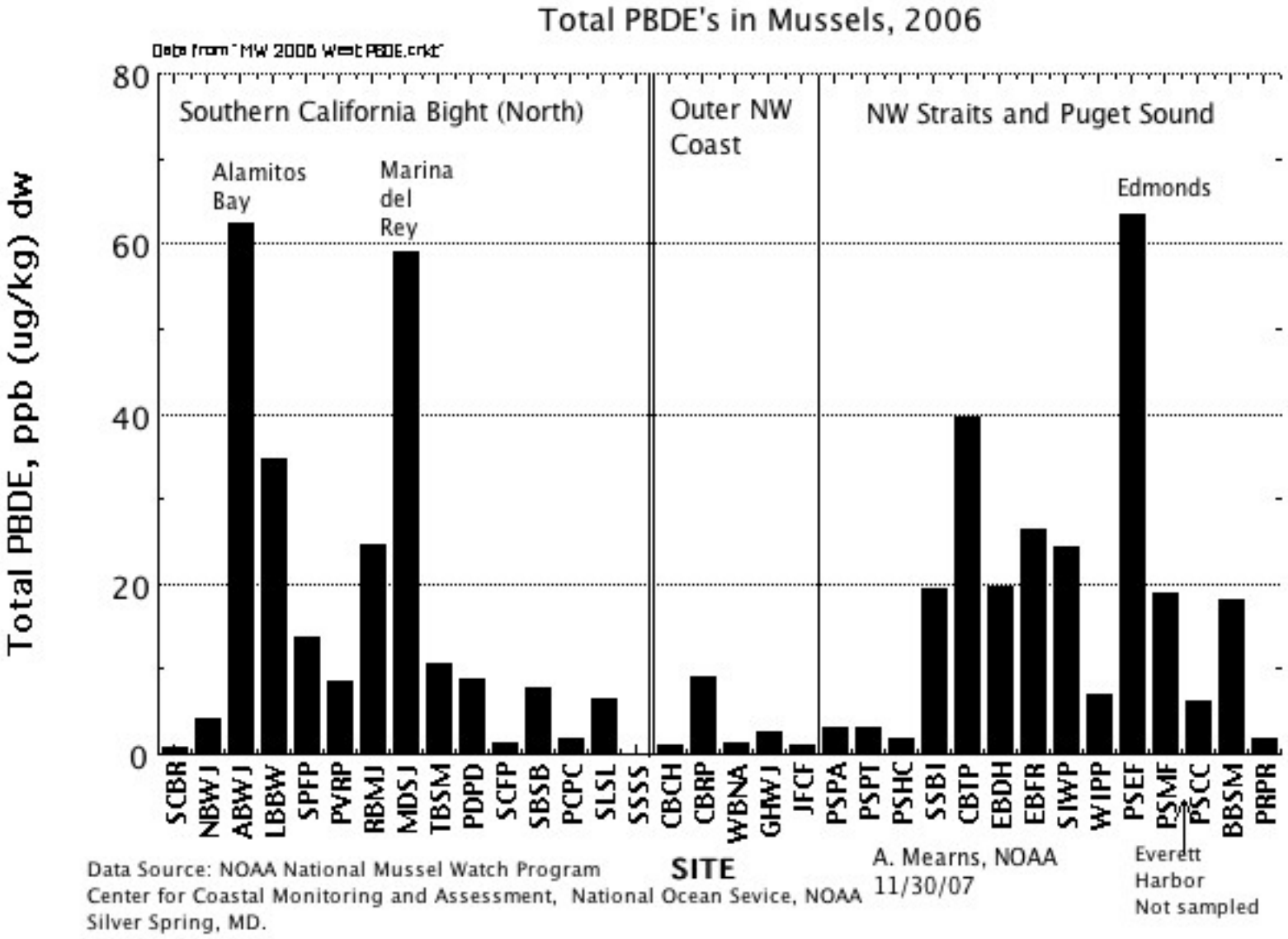
San Diego

PW Sound

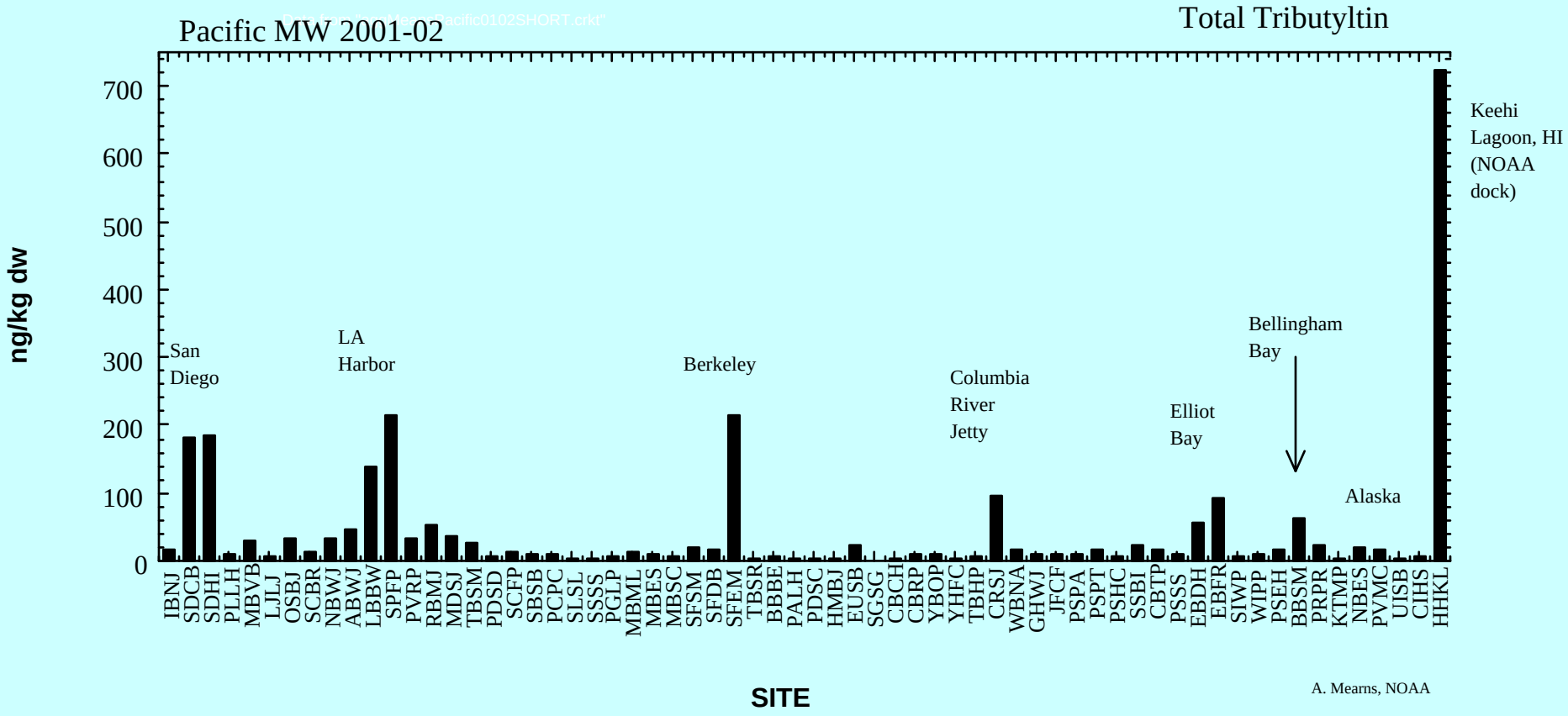
Total (4) Chlordanes in Mussels



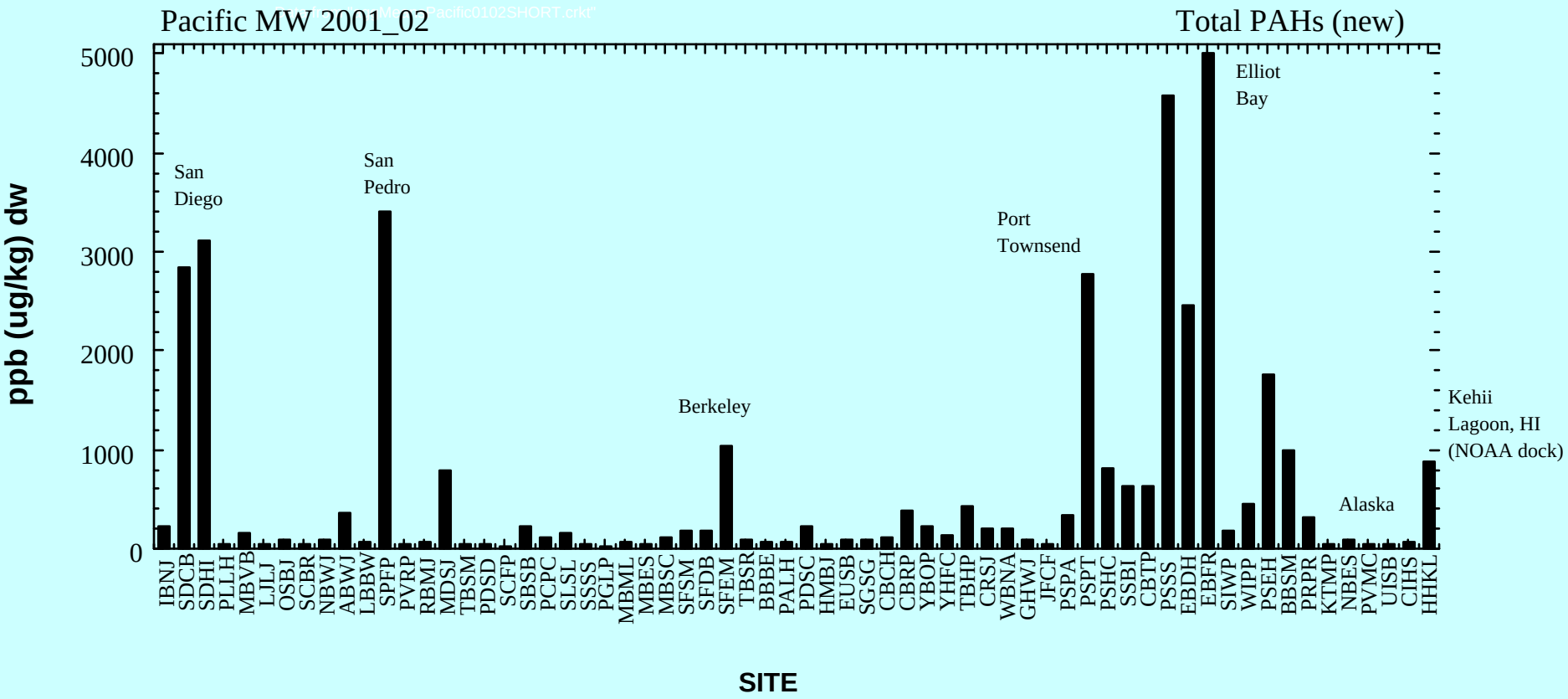
PBDE's


Total PBDE's in Mussels, 2006
Data from "MW 2006 West PBDE.crkt"
Total PBDE, ppb (ug/kg) dw
0
20
40
60
80
Southern California Bight (North)
Outer NW Coast
NW Straits and Puget Sound
Alamitos Bay
Marina del Rey
Edmonds
SCBR
NBWJ
ABWJ
LBBW
SPFP
PVRP
RBMJ
MDSJ
TBSM
PDPD
SCFP
SBSB
PCPC
SLSL
SSSS
CBCH
CBRP
WBNA
GHWJ
JFCF
PSPA
PSPT
PSHC
SSBI
CBTP
EBDH
EBFR
SIWP
WIPP
PSEF
PSMF
PSCC
BBSM
PRPR
SITE
Everett Harbor Not sampled
Data Source: NOAA National Mussel Watch Program
Center for Coastal Monitoring and Assessment, National Ocean Sevice, NOAA
Silver Spring, MD.
A. Mearns, NOAA
11/30/07

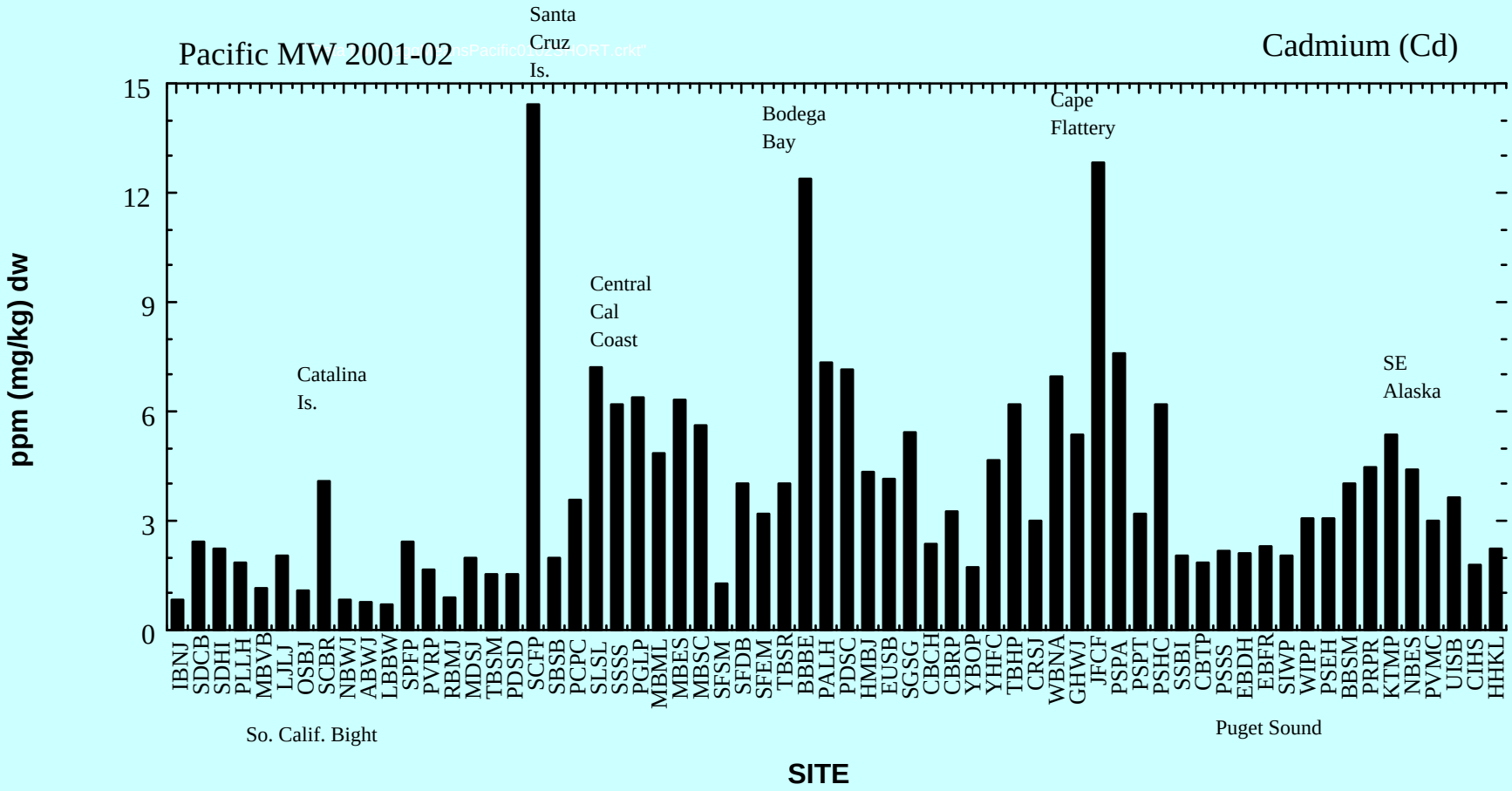
Total Tributyltin (TBT) in Mussels



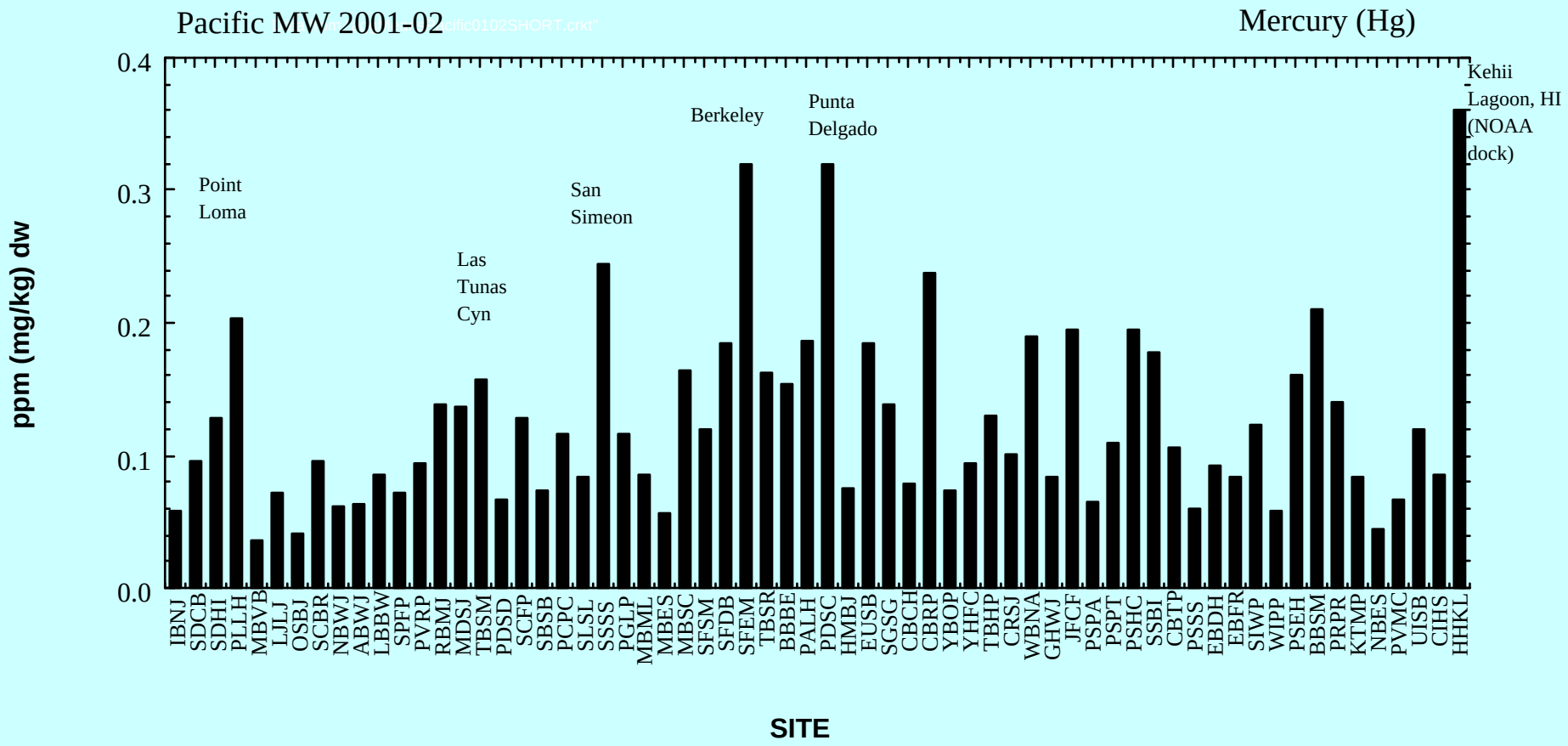
Total PAH's (45) in Mussels



Cadmium in Mussels

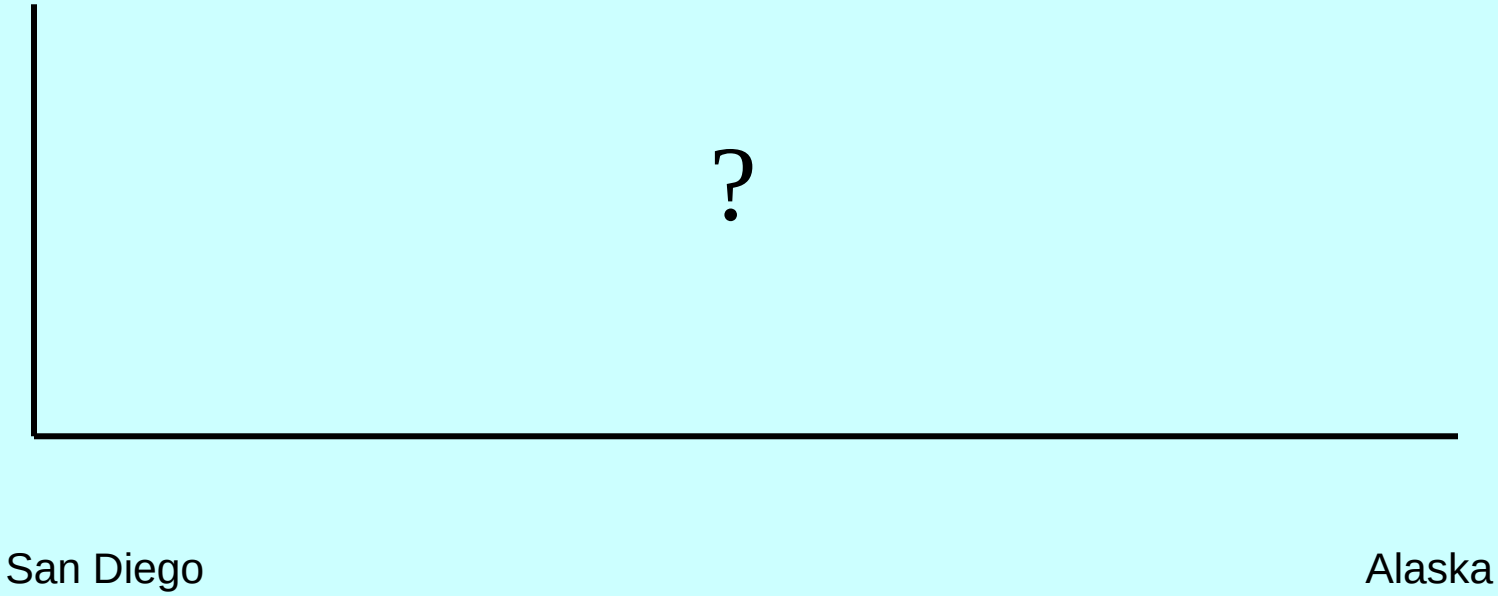


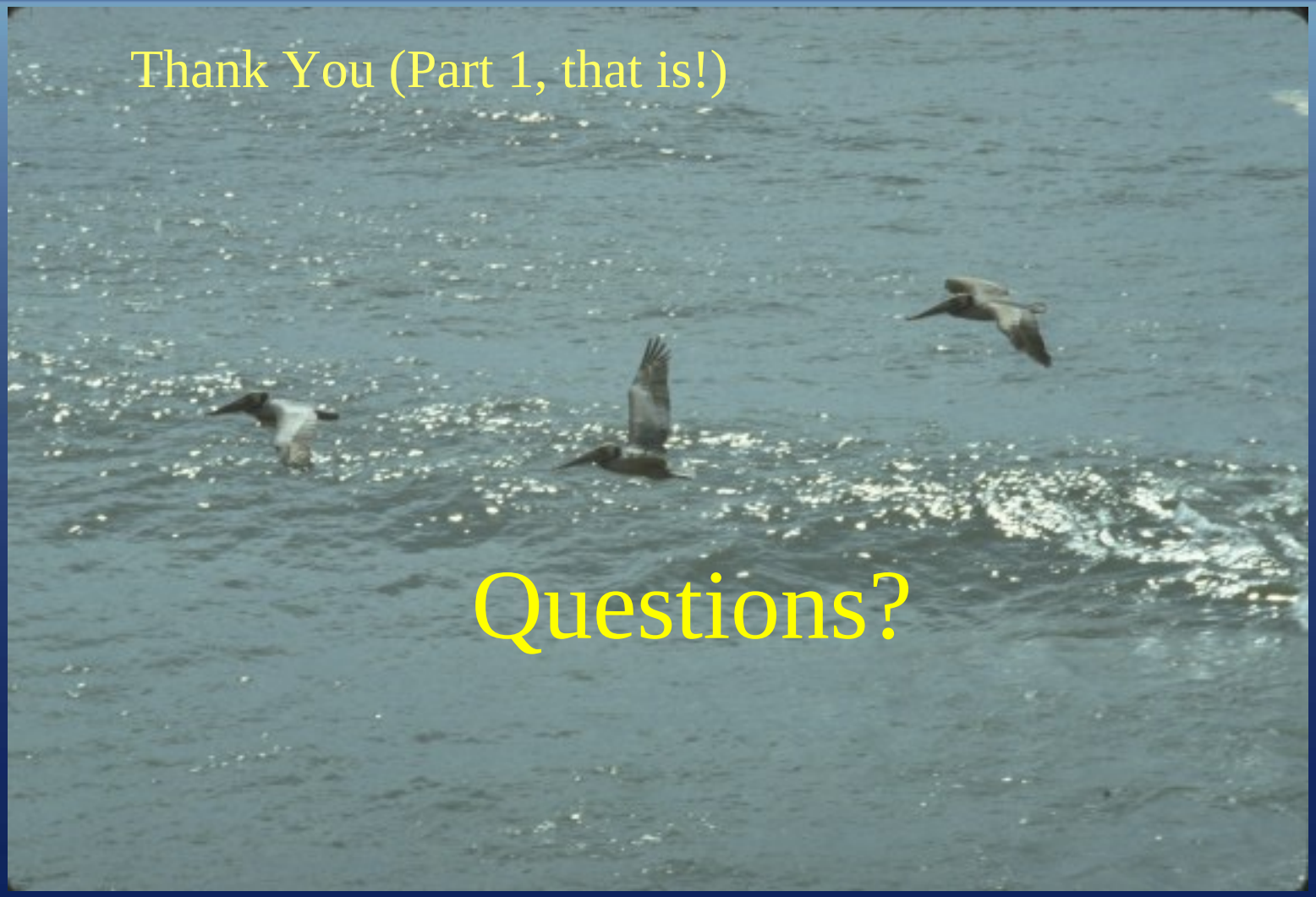
Total Mercury in Mussels



And Finally…….

Total Plastics in Mussels




Thank You (Part 1, that is!)
Questions?

New Presentation:

Frameworks for Assessing and Managing Risks of Microplastic Debris

Alan J. Mearns
Senior Staff Scientist
Emergency Response Division

Office of Response and Restoration
National Oceanic and Atmospheric Administration
Seattle, Washington, USA

- Ecological Risk Assessment Framework
- Oil Spill Response Framework

Risk Assessment

A formal process that defines the probability of adverse effect to humans or to fish or wildlife given exposure to a material or circumstance

Risk Assessment & Management Steps

Hazard Assessment

↓

Exposure Assessment

↓

Risk Assessment

↙ ↘

Risk Communication Risk Management

Why A Risk Assessment Approach?

- Formalizes and Quantifies the problem
- Quantifies Uncertainties
- Forces estimating “How Clean is Clean?”
- Can lead to Innovative Management Solutions
- Identifies collateral impacts of mgmt alternatives
- Formalizes Risk Communications

Examples of Successful(?) Global-Scale Risk Assessments

- Butyltin (TBT) Vessel Coatings
- Organochlorine Pesticides
- PCB's
- Lead

Example of Exposure Assessment

Snowy Plover
Coal Oil Point
Reserve

Tar ball

Density of oil tar on COP Beach = 20 to 150 g/m

Birds are feeding, reproducing, fledging, etc

Exposure Assessment

Where are the birds?

Where are the plastics?

Oil Spill Response Framework

Basic ~~Oil Spill~~ Response Questions

- 1. What got spilled?
- 2. Where is it Going?
- 3. What is the Fate of the oil?
- 4. Who gets hurt?
- 5. What do we do about it?

What Got Spilled? (Oil)

Hazard Assessment

• Light fuels	gasoline, diesel
• Medium fuels and oils	Alaska crude oil, motor oil (10-30W)
• Heavy fuel oils	Bunker C fuel oil
• Asphalt products	asphalts

What Got Spilled? Plastics

Hazard Assessment: Categories

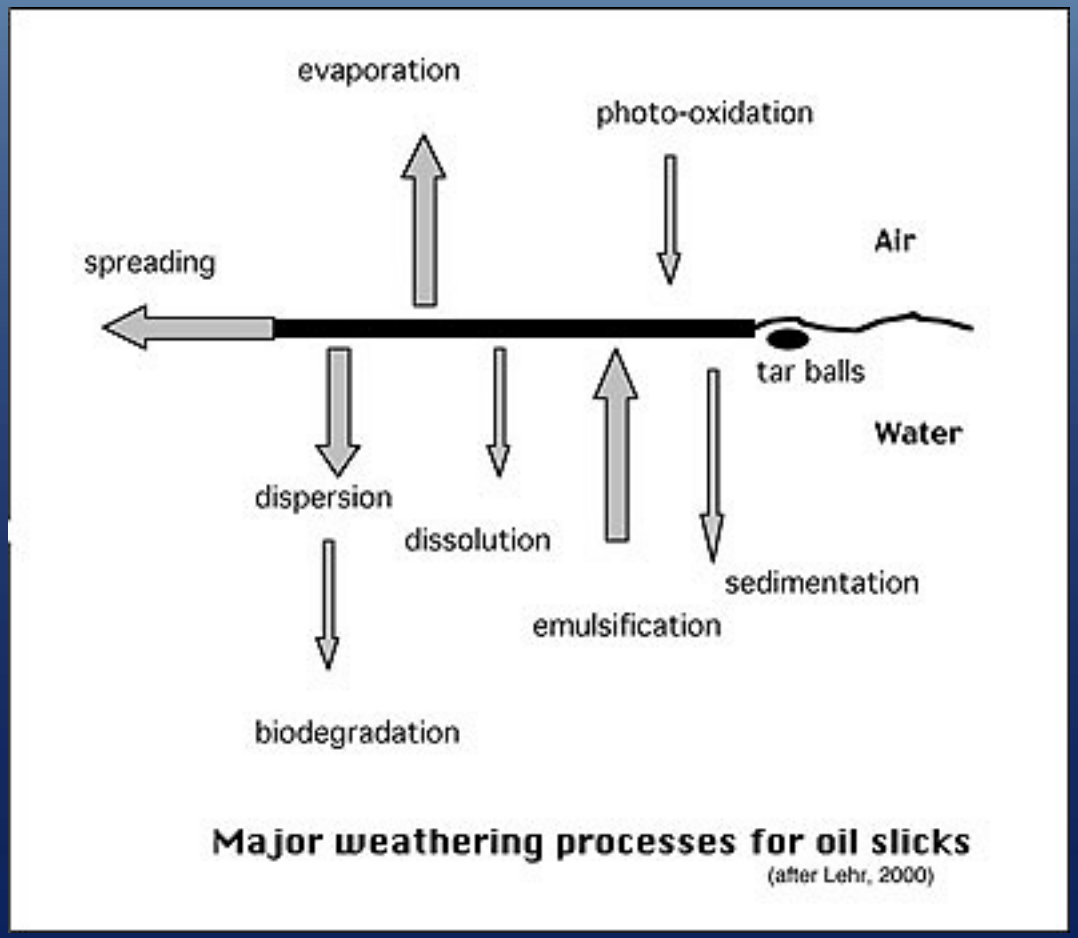
• Polystyrene	containers, etc
• Polypropylene	Fishing gear, etc
• Polycarbonates	????
• etc	????

Where is it going?

Trajectory rules: True of False?

- Plastic floats and sinks
- Spilled plastic will spread rapidly (into surface slicks)
- If there is wind, it will move the plastics down-wind, at 3% of the wind speed (?)
- If the is no wind, the plastics move with the ocean currents
- Microplastics collect in convergence zones

Fates of Spilled ~~Oil~~ Plastics

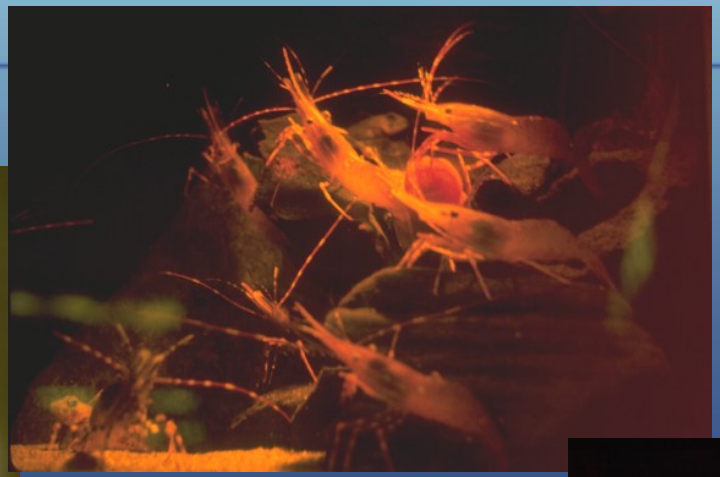


?

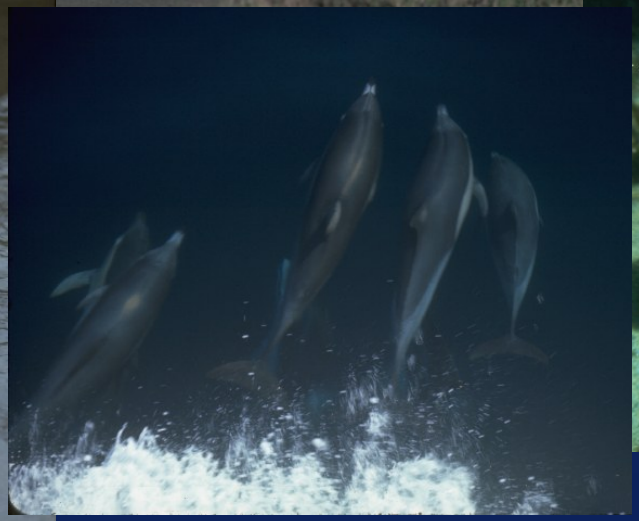
Resources at Risk

- Sea birds, mammals
  - Oil sticks to fur and feathers
  - Causes animal to loose warmth
- Fish
  - Not a problem unless oil dispersed into the water
- Beach and Shoreline Marine Life
  - Sandy beach — least sensitive
  - Rocky shorelines — moderately sensitive
  - Marshes — very sensitive to any disturbance

Trophic Levels II & III



Trophic Levels II, IV & V



Response (Management) Options: Open Water

• Do nothing	Hazard Quotient is low
• Mechanical (skimming)	Birds do it
• Burning	?????
• Dispersion	???
• Flocculation	??

Response Options: Shorelines

• Do Nothing	Hazard Quotient is low
• Manual Cleaning	(screens, absorbents, ?)
• Mechanical	washing, floatation, ??
• Chemical cleaners	?
• Bioremediation	Nutrients?

So, How do we Organize Plastics Spill Response?

ICS: Incident Command!!!

Incident Command Benefits

- Brings RP and Trustees to Central Location
- Uses State of the Art Information Management
- Focuses on Resources at Risk
- Employs Standardized Observation methods
- Manages Costs
- Provides Logistics
- Identifies How Clean is Clean, Signoff Criteria
- etc

noaa

Thank You form Listening

noaa

Finally….

Prevention……..

Monitoring ?

ysters

A. Mearns

Example: Evaporation (on water)

- Light Oils (Plastics?)
  - Gasoline 100% in less than one hour
  - Diesel fuel 100% in about a half day
- Medium Oils and Fuels (Plastics?)
  - Alaska crude oil 25% in a day
- Heavy fuel oils (Plastics?)
  - Bunker oil less than 5% in two days

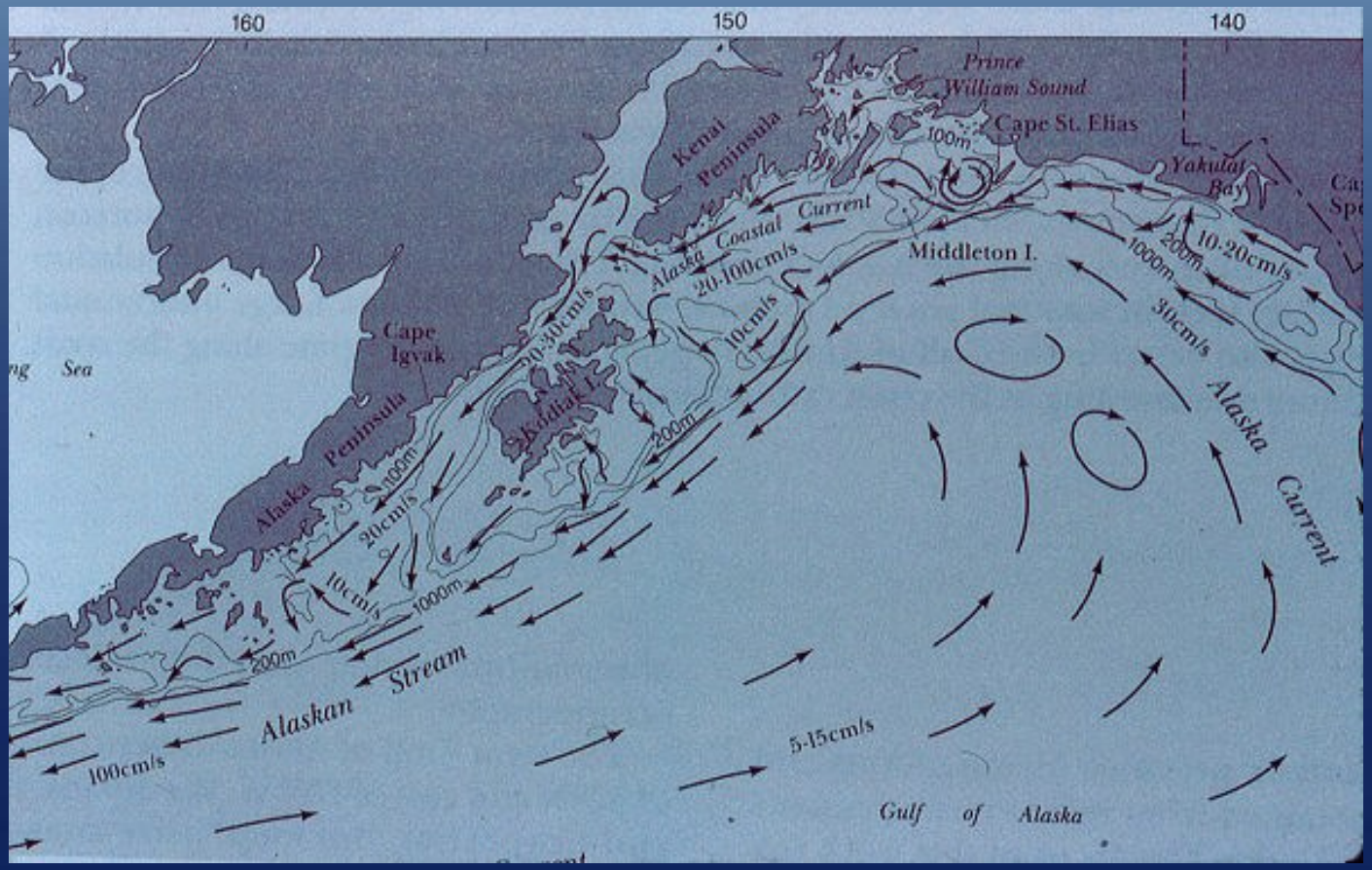
- …Or, the presentation I don’t want to give….!!

So, why not take an ecological risk assessment and management approach?

Fates of spilled plastics?

- Spreading
- Concentration
- Evaporation
- Dispersion
- Emulsion (?)
- Stranding on shore lines
- Incorporation in food web

Alaska's Ocean Currents



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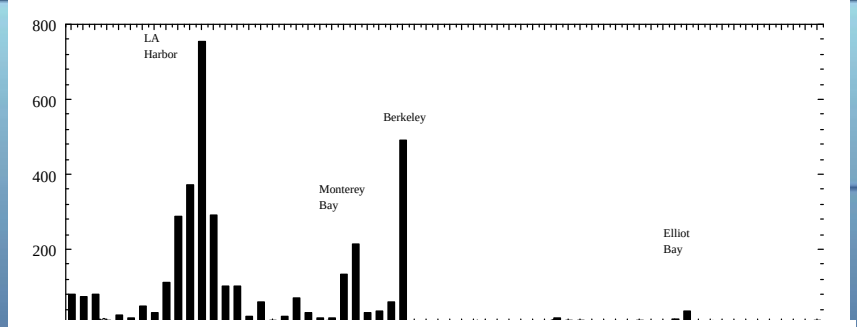
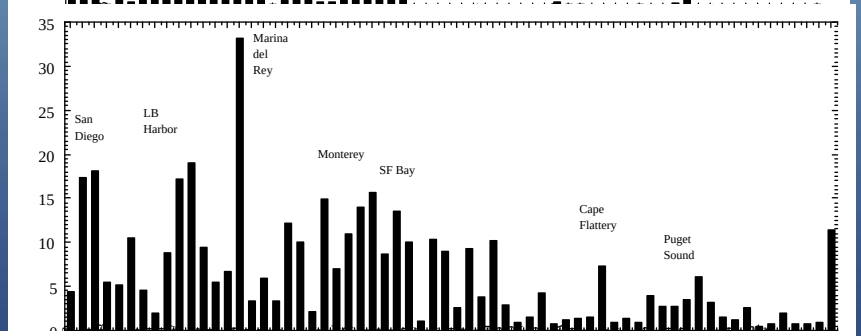
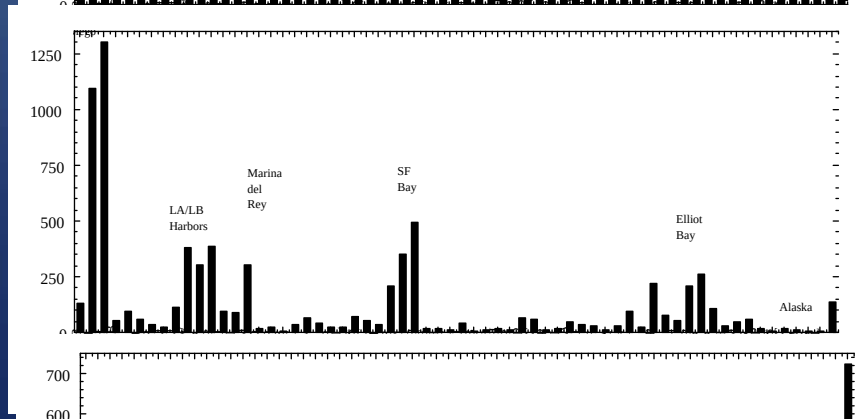


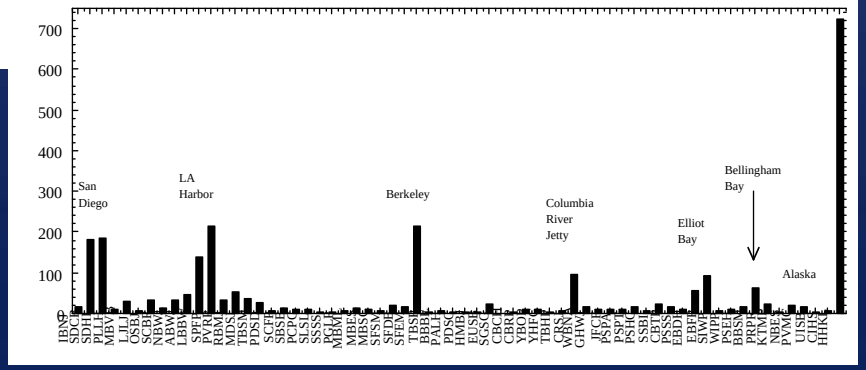
DDTs



Chlordanes

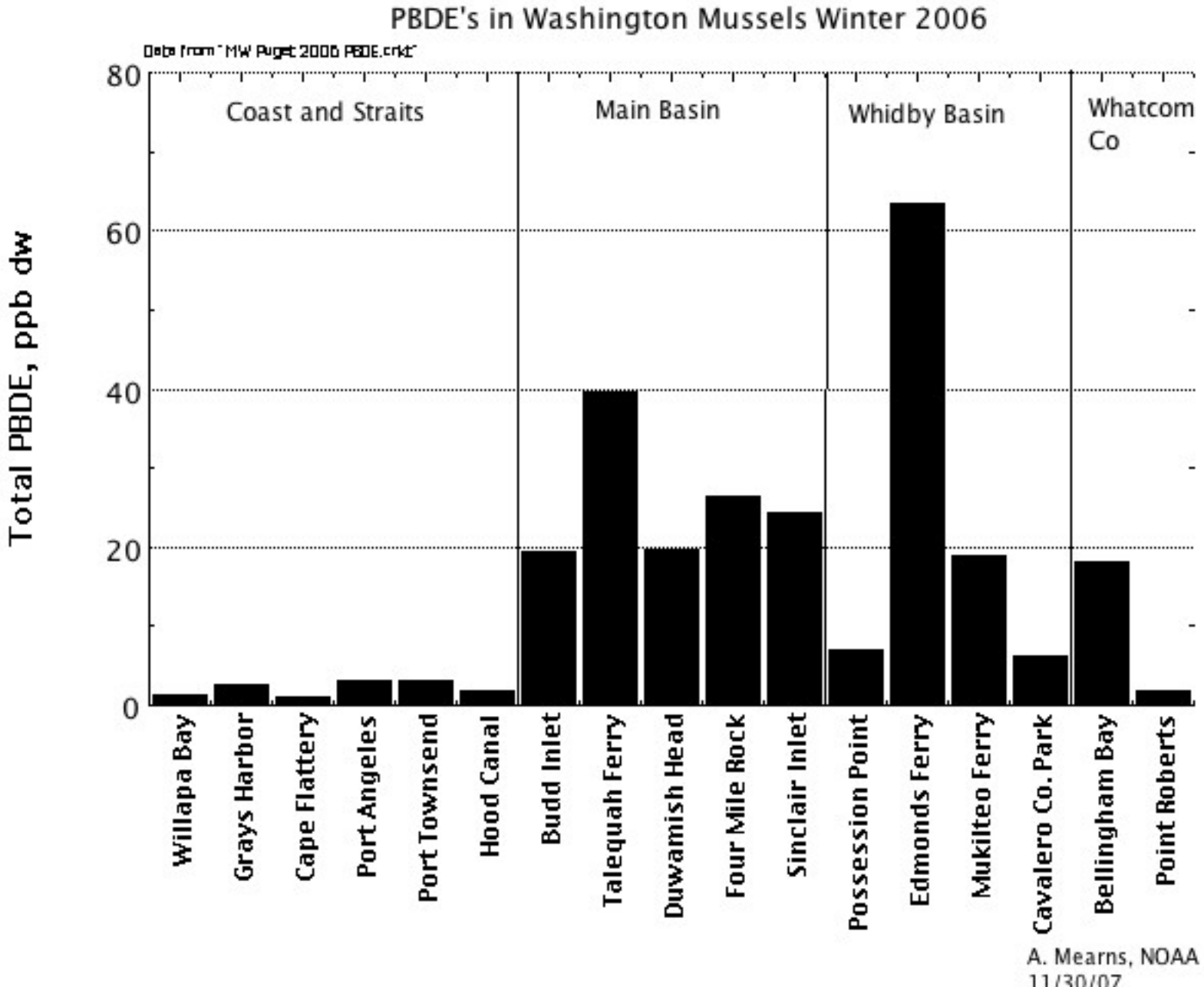


PCBs



TBTs

PBDE's


PBDE's in Washington Mussels Winter 2006
Data from "MW Puget 2006 PBDE.crkt"
Total PBDE, ppb dw
80
60
40
20
0
Coast and Straits
Main Basin
Whidby Basin
Whatcom Co
Willapa Bay
Grays Harbor
Cape Flattery
Port Angeles
Port Townsend
Hood Canal
Budd Inlet
Talequah Ferry
Duwamish Head
Four Mile Rock
Sinclair Inlet
Possession Point
Edmonds Ferry
Mukilteo Ferry
Cavalero Co. Park
Bellingham Bay
Point Roberts
A. Mearns, NOAA
11/30/07

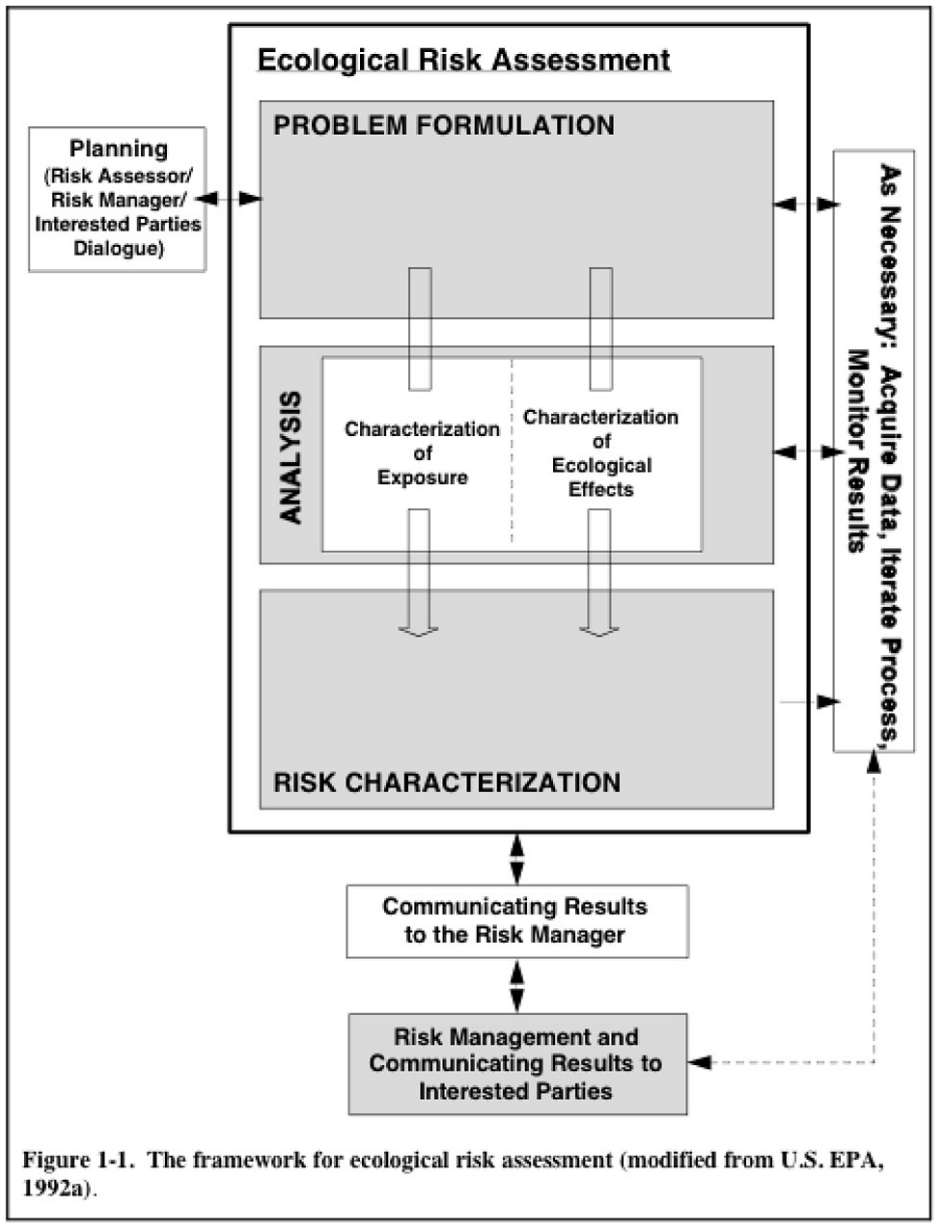
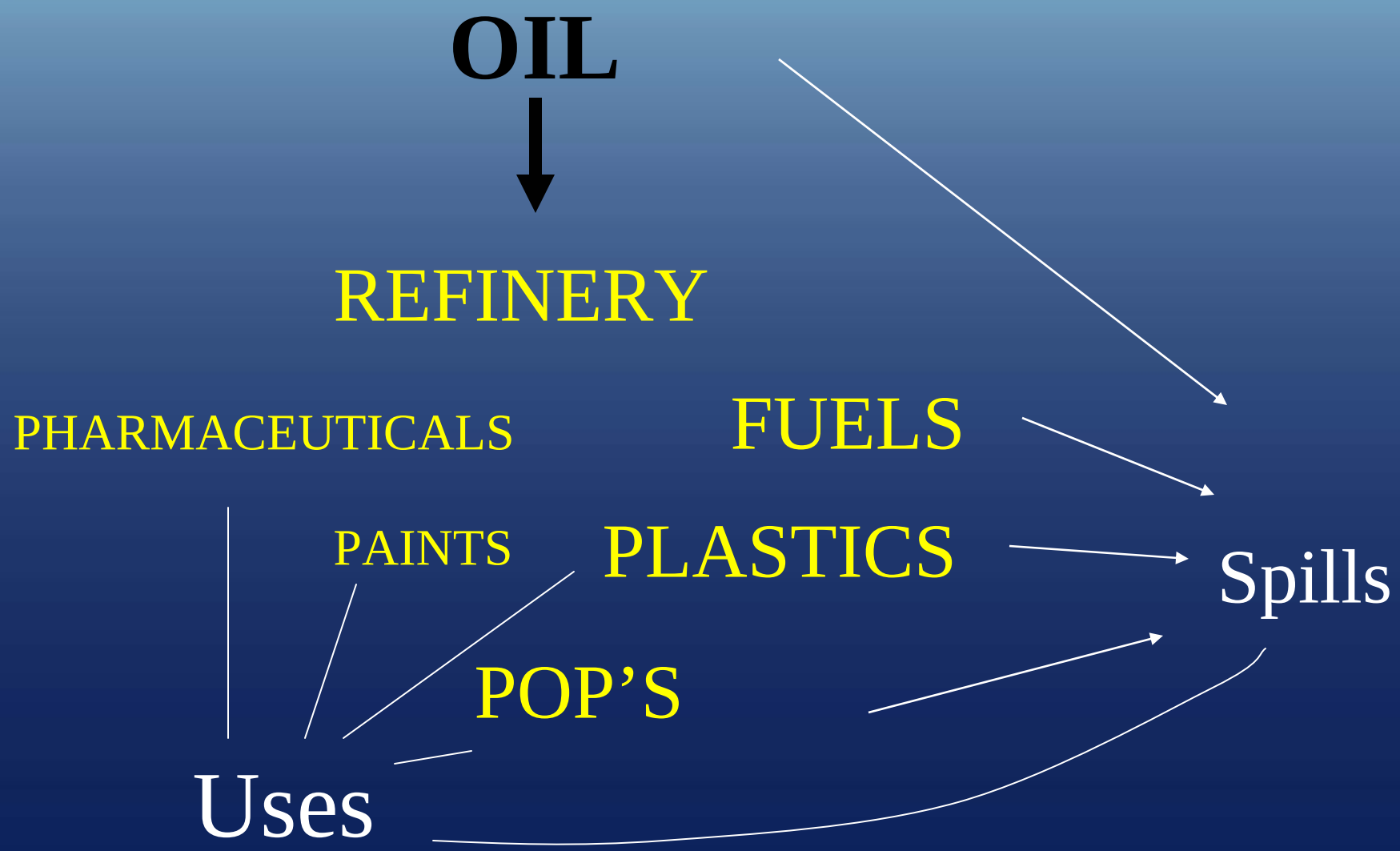


Figure 1-1. The framework for ecological risk assessment (modified from U.S. EPA, 1992a).

Plastics in the Scheme of Things



Nurdles

- 5 mm, 20 mg
- 60 billion poun

The oceanography, biology, and fisheries of the North Pacific

Dr. Michael P. Seki, NOAA National Marine Fisheries Service, Honolulu, HI

Abstract: An overview of the oceanography and living resources of the North Pacific Ocean is presented. In particular, physical processes such as large scale ocean circulation patterns and semi-permanent frontal systems that play key roles in facilitating the accumulation of marine debris are highlighted. Seasonal and meso-scale variability of ocean processes give rise to localized "hot spots" of convergence and enhanced biological aggregations. And an examination of the basin-wide Transition Zone Chlorophyll Front depicts a region where surface feeding animals are particularly vulnerable to marine debris accumulation.

Michael P. Seki, PhD, is the Deputy Director of the Pacific Islands Fisheries Science Center located in Honolulu, Hawaii. He is a career government employee having been with NOAA Fisheries since 1980. As a research scientist over the past 27 years, he has conducted studies on marine resources in the Pacific region including seabirds, sea turtles, tropical snappers, oceanic squid, tunas, and billfishes, and has authored or co-authored over 40 scientific papers on topics such as open ocean food webs (ecosystems) and the influence of the physical oceanographic environment on the distribution and abundance patterns of living marine marine resources.

Born and raised in Hawaii, Dr. Seki received his B.S. in biology from the University of Oregon, his M.S. in oceanography from the University of Hawaii, and his Ph.D. in marine environment and resources from Hokkaido University (Graduate School of Fisheries Science); with a dissertation topic focused on how living marine resources in the North Pacific respond to abrupt changes in oceanographic conditions.

The oceanography, biology, and fisheries of the North Pacific

Michael P. Seki

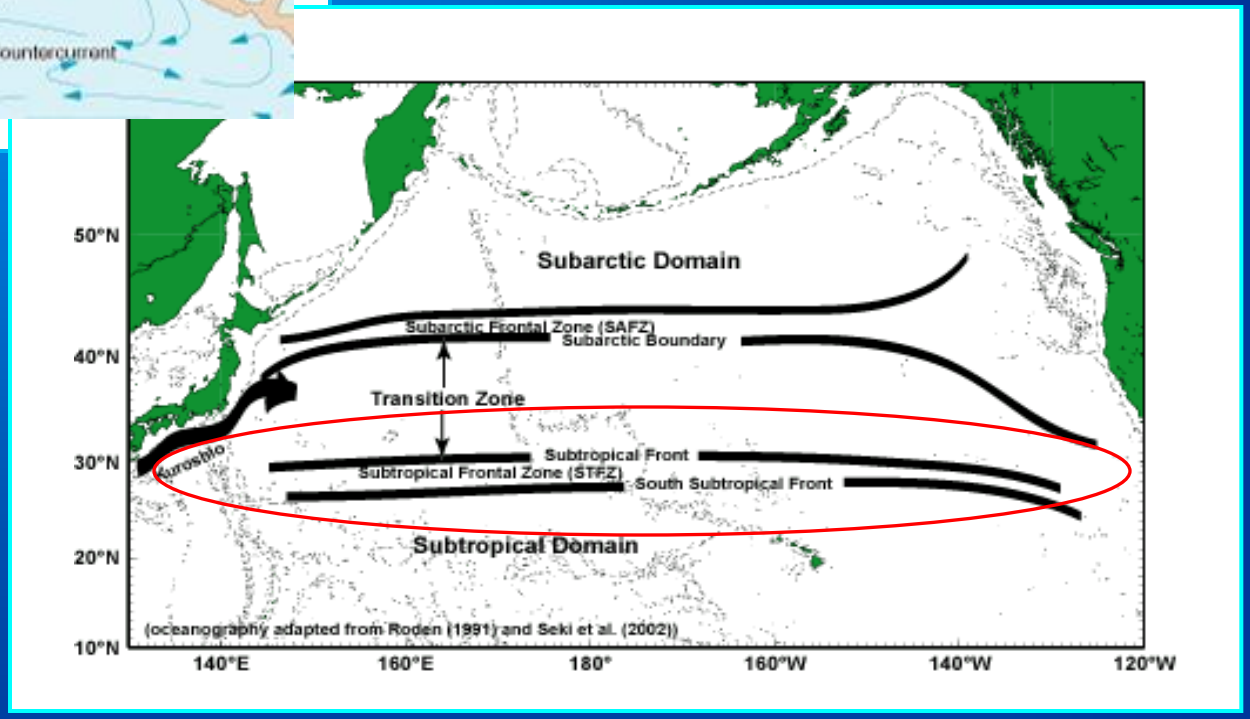
National Marine Fisheries Service, NOAA
Pacific Islands Fisheries Science Center
2570 Dole Street, Honolulu, HI 96822-2396

Workshop on Microplastic Marine Debris
9-10 September 2008

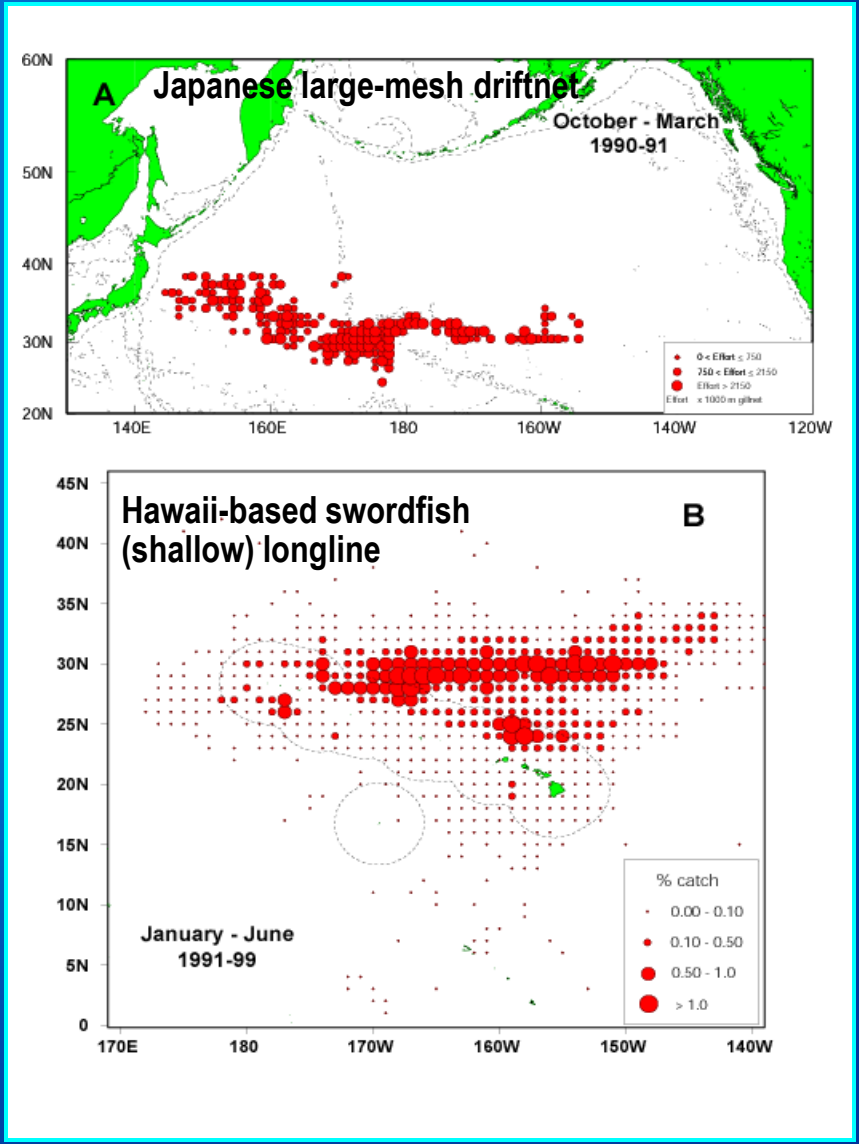
Overview

- A question of scale?
  - Gyre circulation
  - Basin- scale fronts
  - Mesoscale meanders & eddies
- … and why do we care?
  - Regions of Convergence & Divergence
  - Energy (trophic) transfer dynamics
  - Natural hotbeds for fisheries, marine mammals, sea turtles, & seabird interactions

Large scale oceanography



Fisheries interest at North Pacific Frontal Zones:



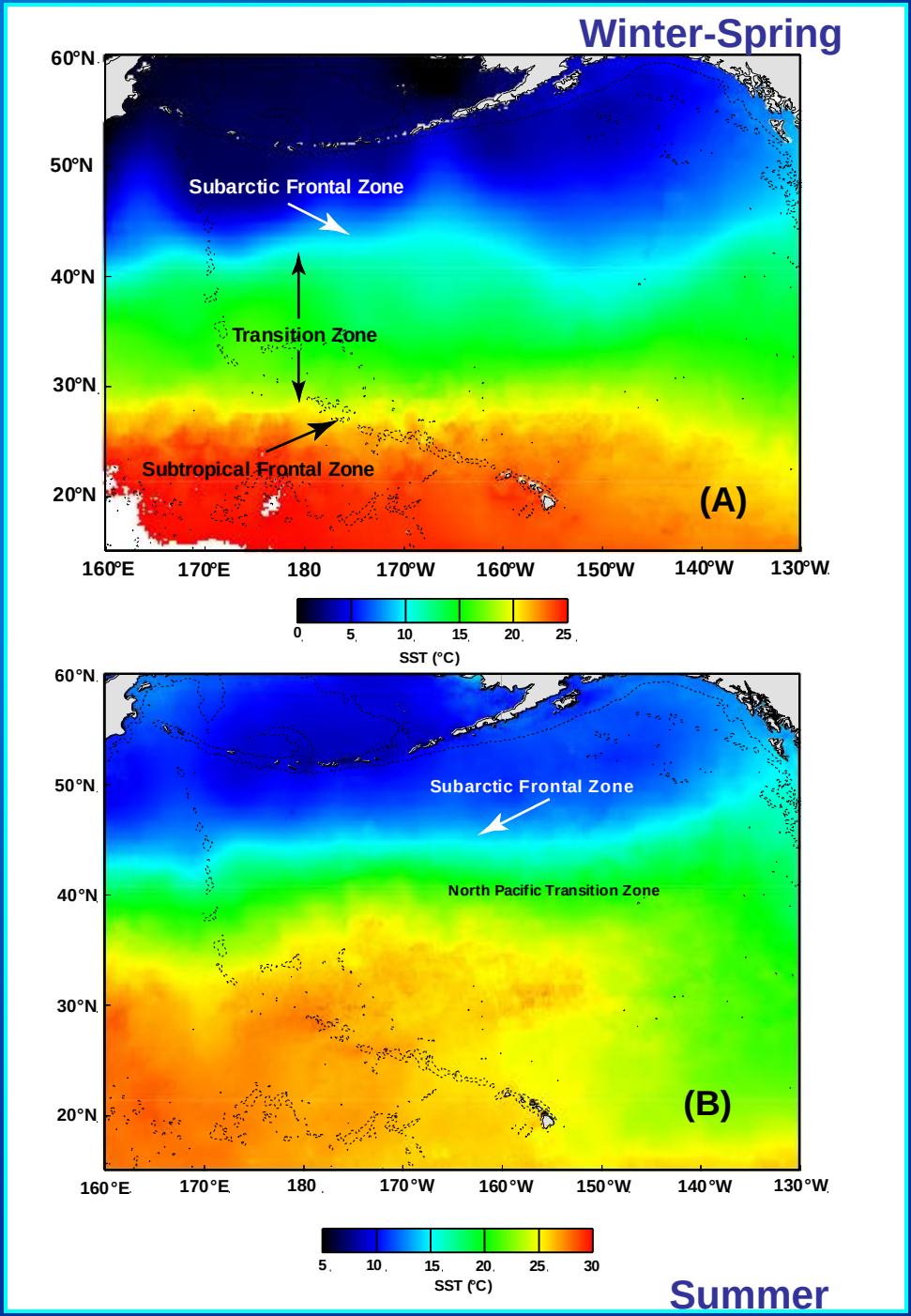
*Fisheries operating at Subtropical Frontal Zone waters:

- U.S., Japan, et al. longline fisheries
- U.S., Japan troll fisheries for tuna (albacore)
- Japan distant water squid jigging fishery
- [former] high seas Asian driftnet fisheries (squid & large mesh)

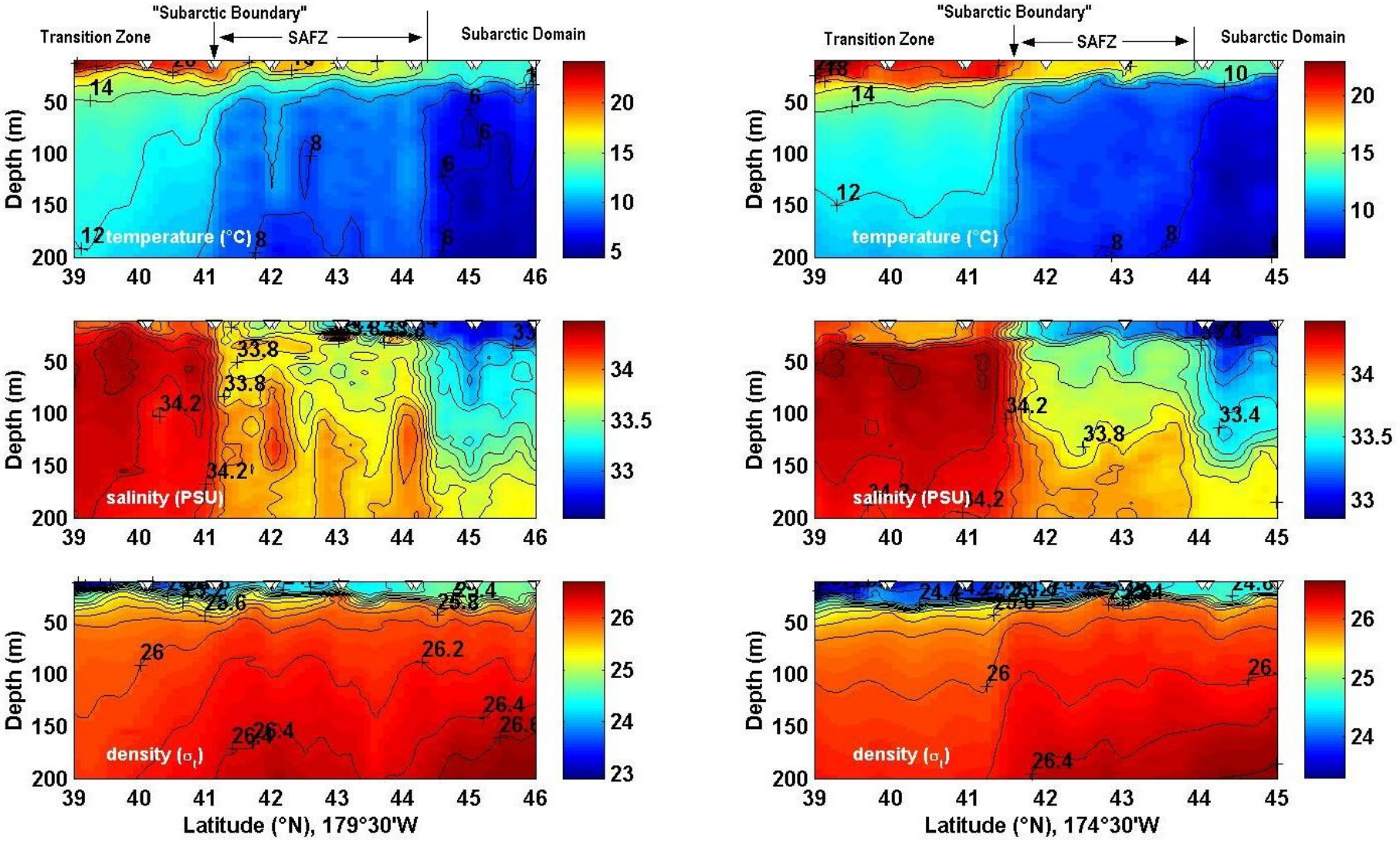
* Many Transition Zone nektonic species undergo extensive seasonal migrations bound by the STFZ

Basin-scale Frontal Zones

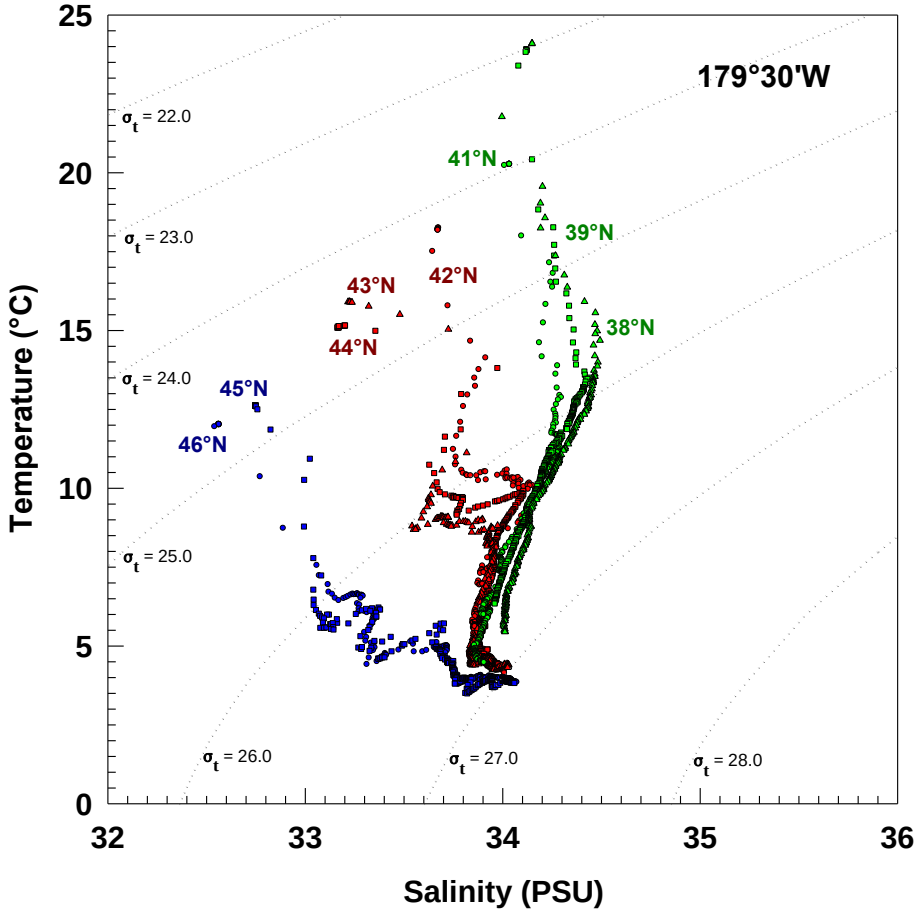
- Distinct seasonal surface signatures
- Concentration of thermohaline gradients result from convergence of Ekman flow
- Multiple large scale fronts (e.g. STFZ)
  - SSTF: 28°- 30°N
  - STF: 32°-34°N
- Pervasive mesoscale (10-100 km) processes on synoptic time scales
- SLH fluctuations = surface expressions readily measured by satellite altimeters

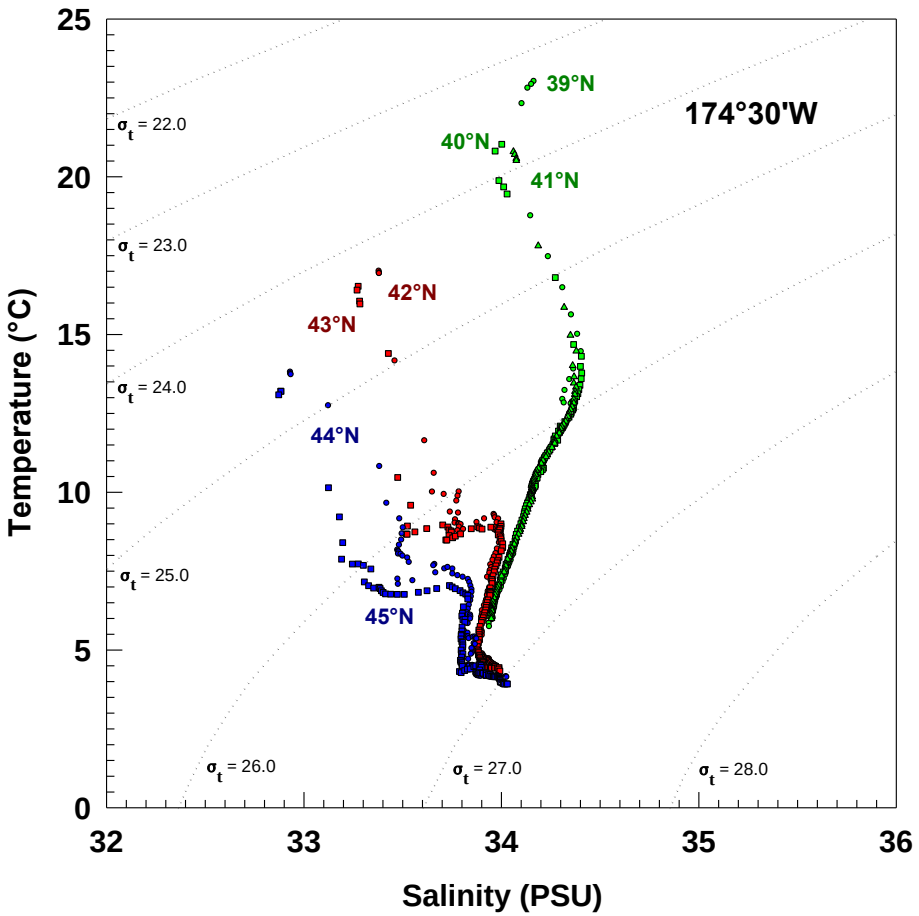


Vertical sections (t, S, σ_t) through the SAFZ at 179°30'W and 174°30'W



T-S plots for 1° CTD stations through the SAFZ at 179°30'W and 174°30'W



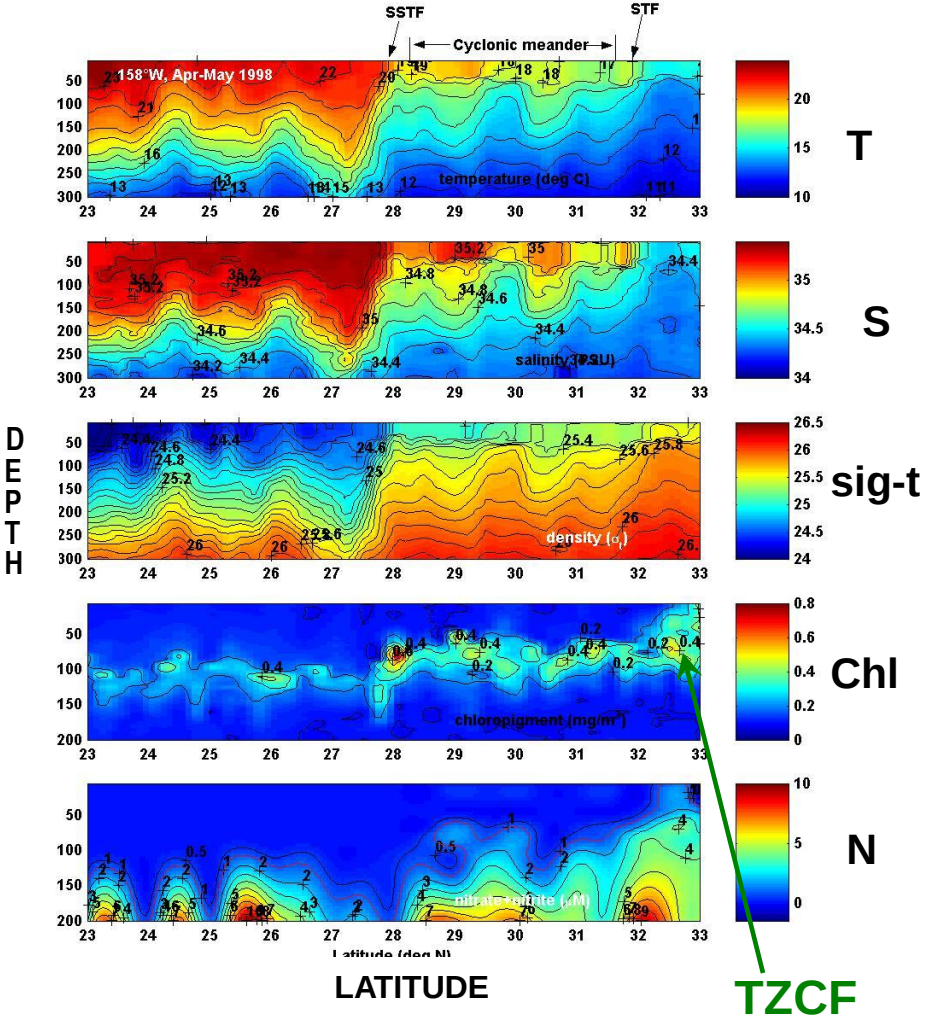


- In situ section (1,140 km) along 158°W
- SSTF near 28°N lat.; STF just north of 32°N lat.
- Cross frontal gradients steepest at SSTF where:

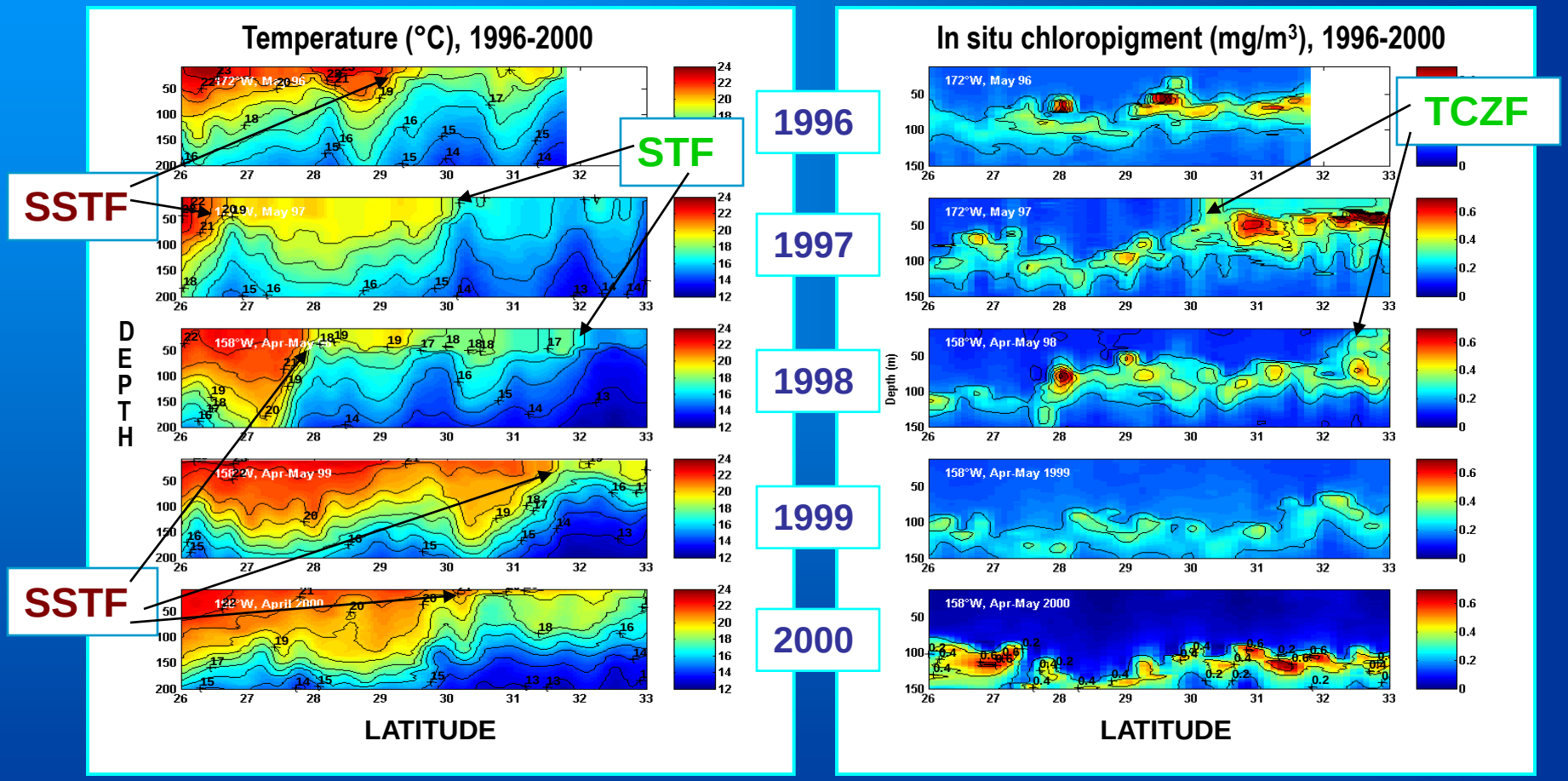
  $\Delta T \sim 3$ C/50 km
  $\Delta S \sim 0.7$/50 km
  Δsig-t~0.6/50 km

- Cyclonic meander evident near 29 N
- Z_{SCM}, & nutricline shoaled and closely tracked corresponding density structure
- $[Chl_{SCM}] > 1.0$ mg/m^3 at SSTF. Note increased productivity occurs subsurface at SSTF and is not detectable by satellites
- STF marks transition from low, nutrient depleted waters to the south to 2-fold increase to the north; i.e., TZCF

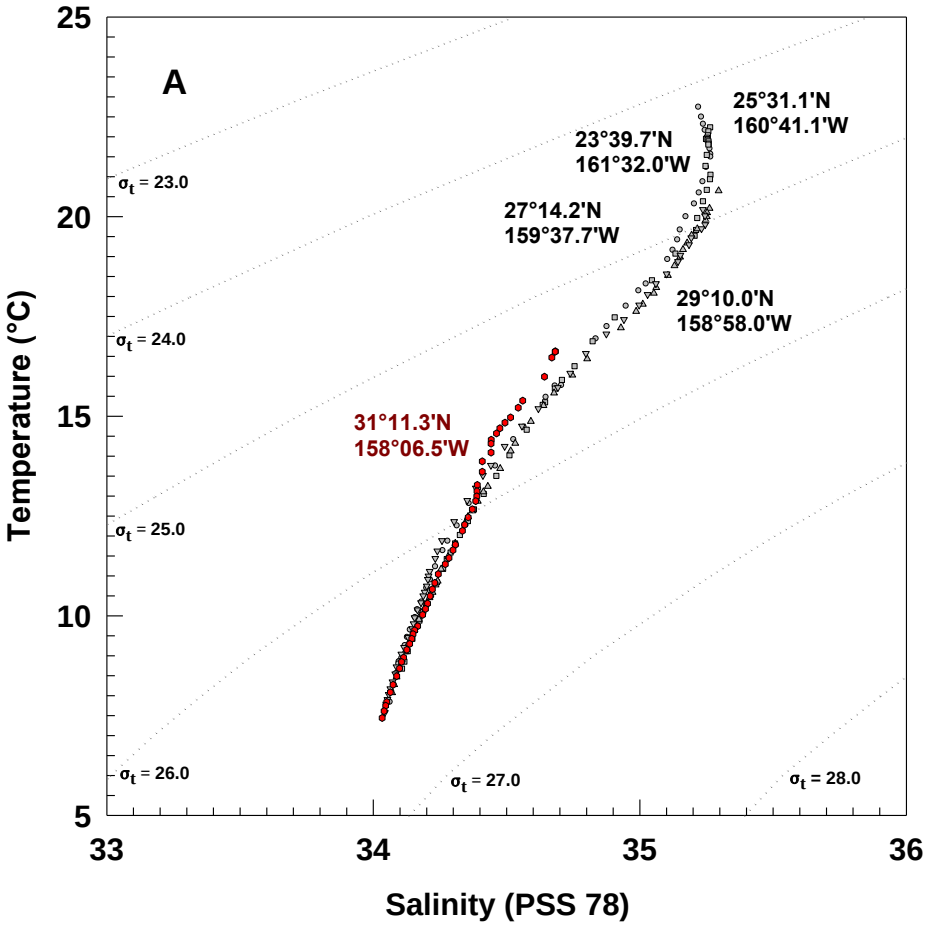
April-May 1998

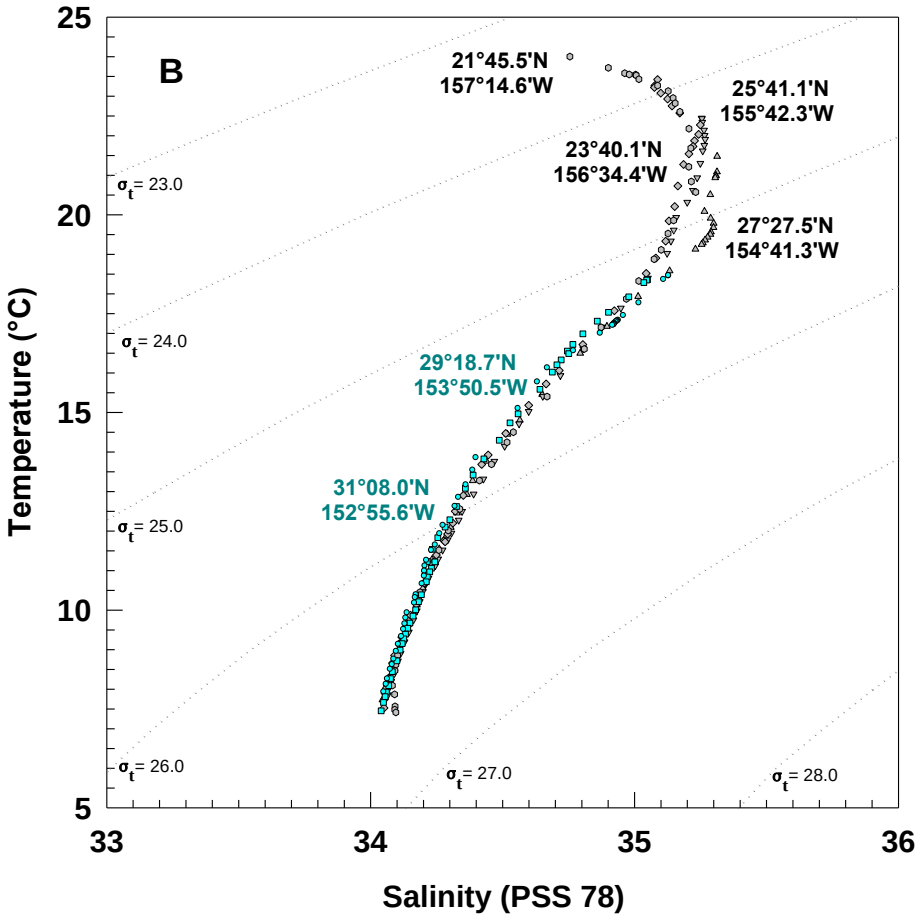


Considerable interannual variability in latitudinal position and intensity of the SSTF & STF; ca. 300 km shift in frontal positions between 1996-97 at 172°W and 1998-99 at 158°W.

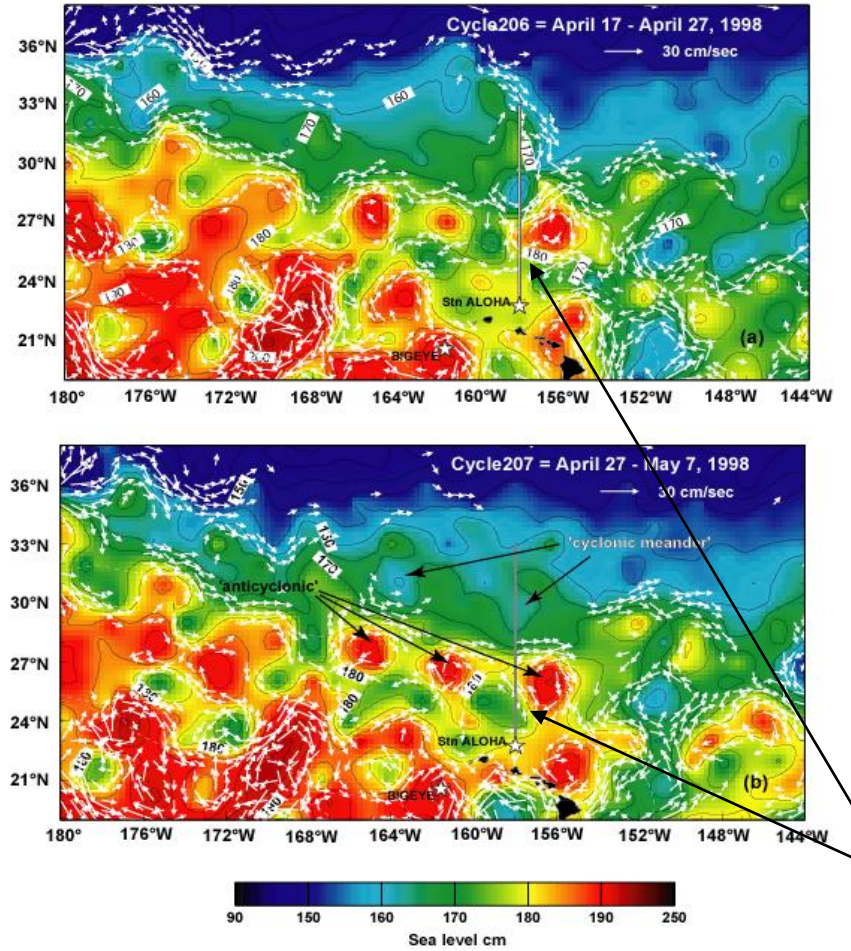


T-S plots for trawl station CTDs through the STFZ





Topex altimetry – April 1998

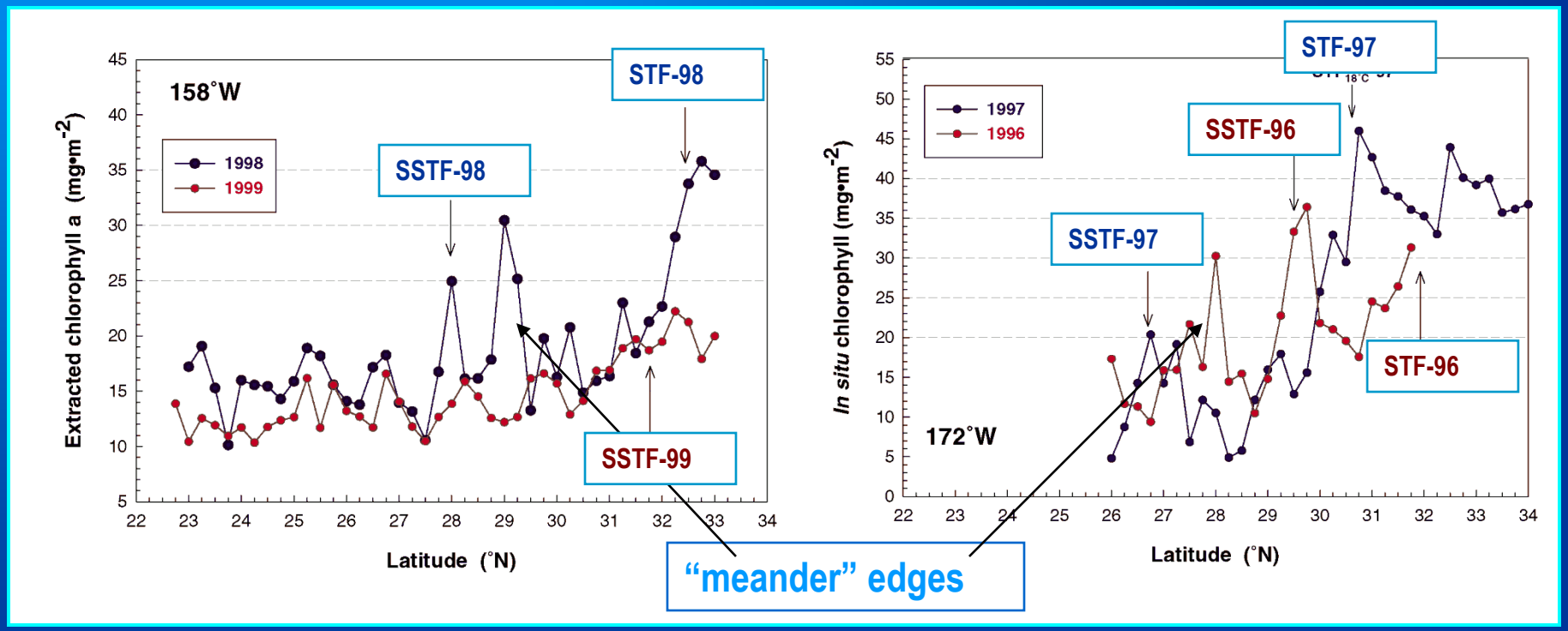


- STFZ: characterized by pervasive field of mesoscale activity (e.g., meanders, eddies, jets) in various stages of formation & decay
- Influence of Kuroshio Extension
- Cyclonic eddies & meanders prevalent to the north of streamlines; anticyclonic to the south
- Note cyclonic meander centered near 29°N lat.

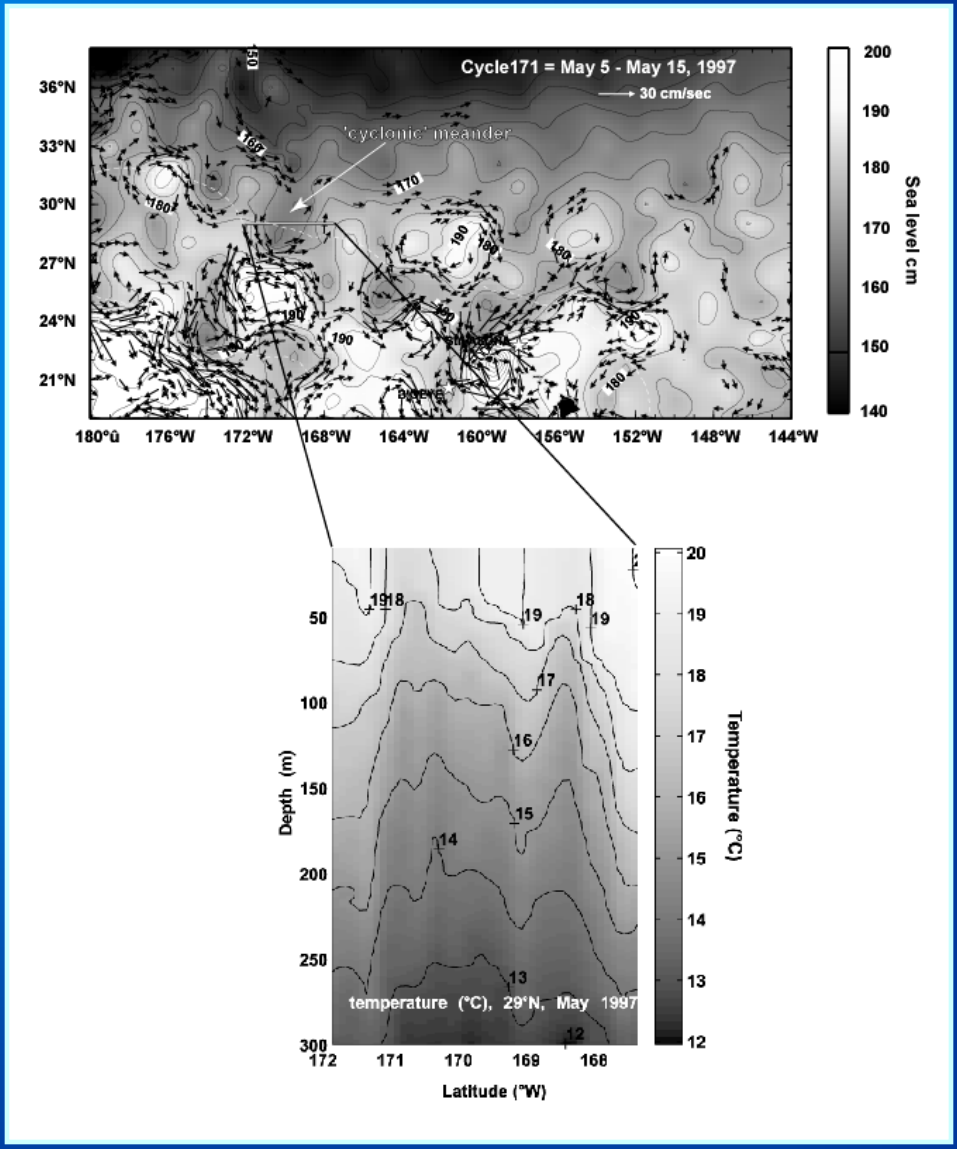
"Position of survey transect line"

Fronts and embedded mesoscale features are key to biological enhancement:

- Integrated chloropigment exhibit distinct maxima in alignment with SSTF & STF
- Can be ascribed to increases in the concentration & thickness of SCM layer
- Chloropigment levels especially amplified by displacement of isopycnals in presence of meanders.

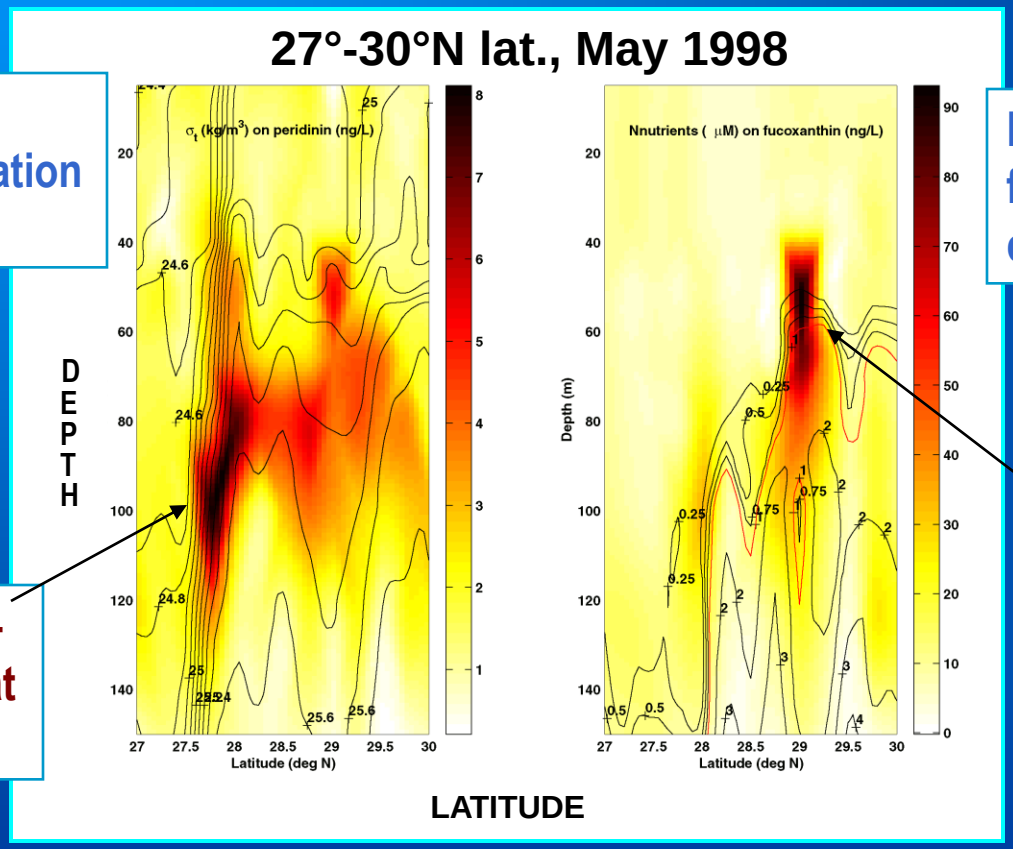


Vertical temperature (°C) distribution from zonal slice through a cyclonic meander at 29°N lat, May 1997.



Enhanced chloropigment responses to physical environment also reflect substantial increases in large eukaryotic phytoplankton; namely diatoms & dinoflagellates, suggesting enhanced transfer efficiency to higher trophic levels at these dynamic areas.

Isopycnals (σ_t) on peridinin concentration (mg/m^3)



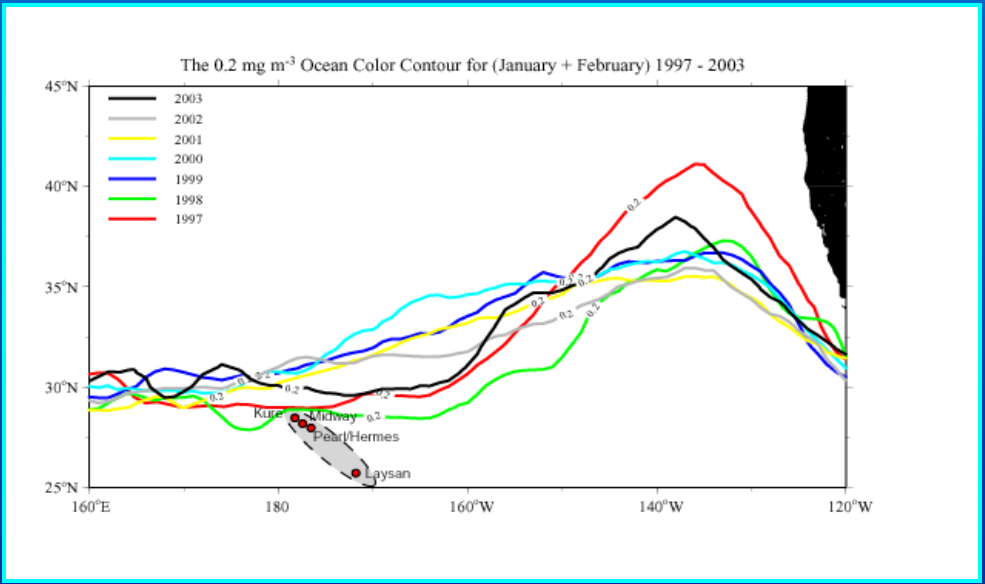
N+N isopleths on fucoxanthin concentration (mg/m^3)

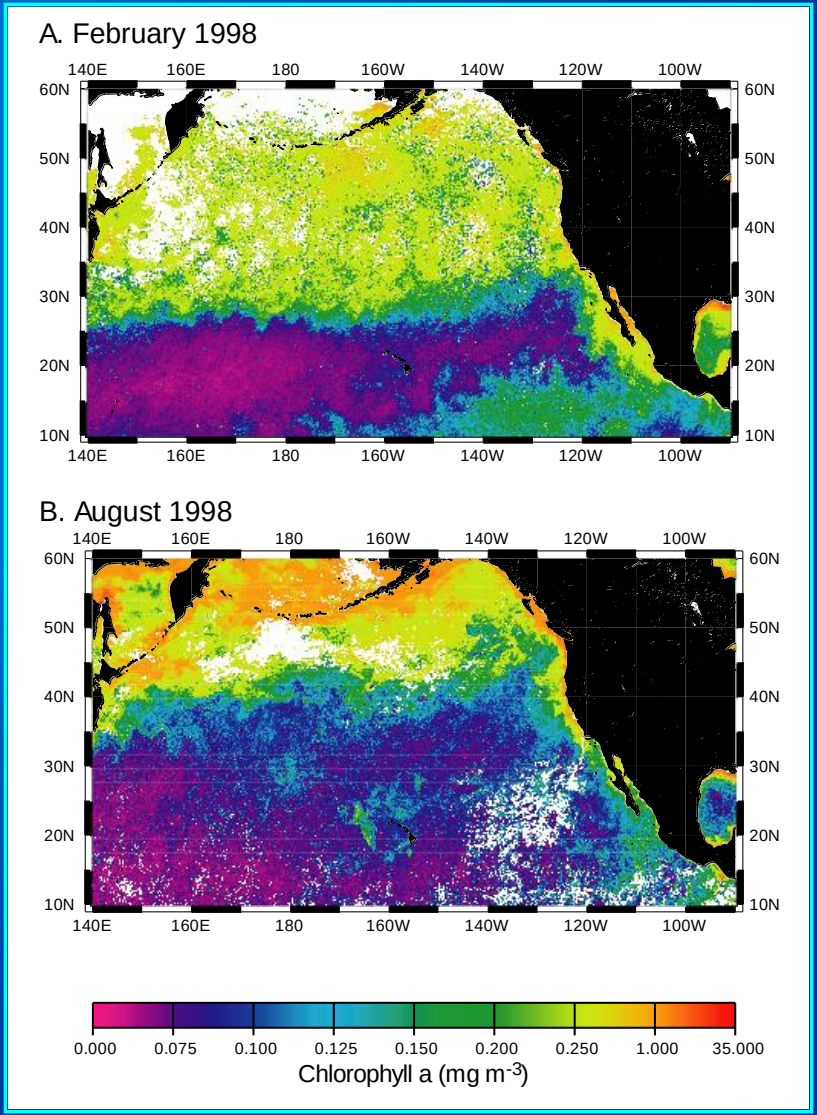
SSTF interface – note increases at depth!

Embedded cyclonic meander … red contour is nutricline defined as 1M N+N isopleth

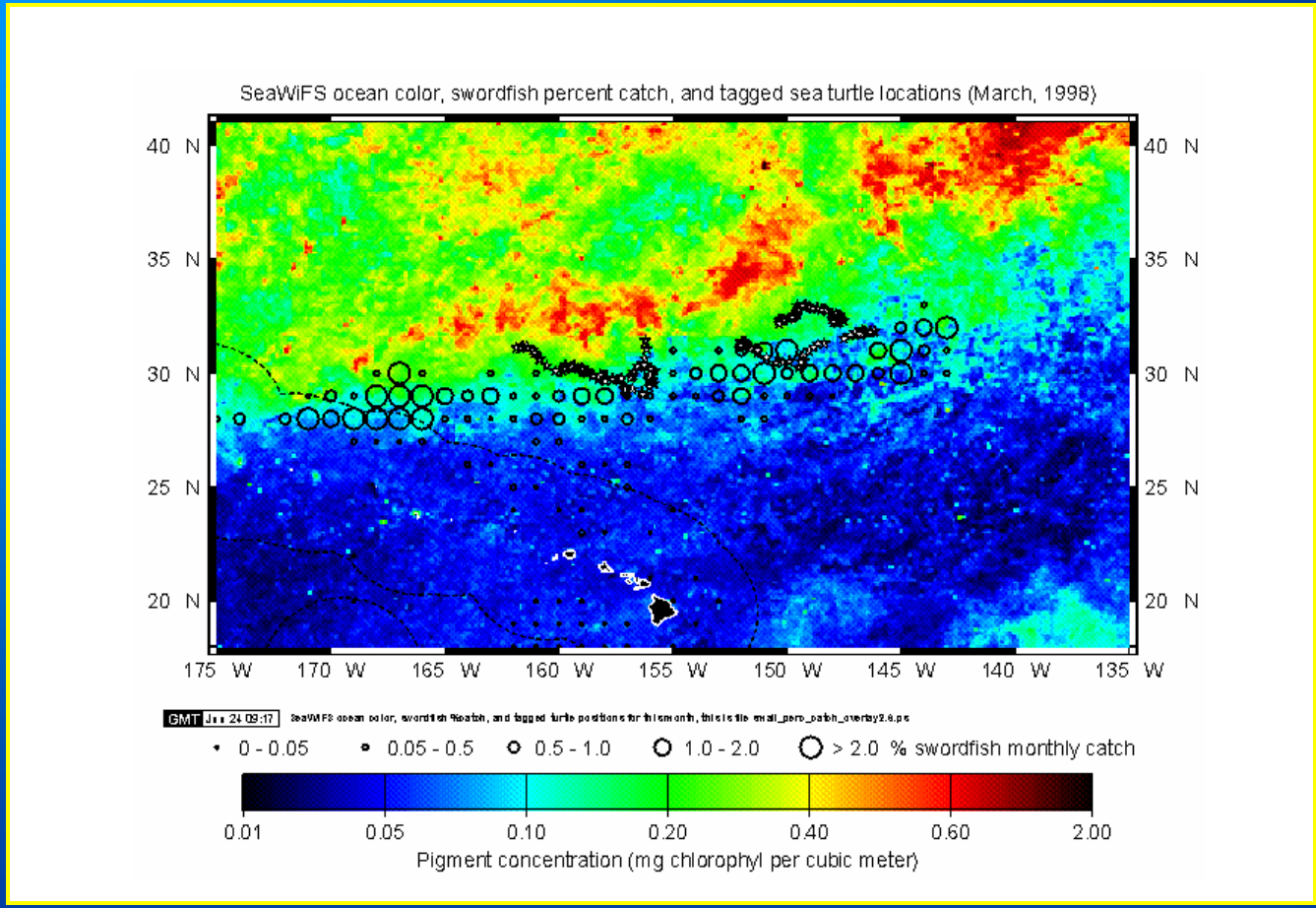
The North Pacific Transition Zone Chlorophyll Front

- Basin-scale feature defined by the 0.2 mg/m^3 Chl surface contour
- Seasonally oscillates north to south about 1000 km with a latitudinal minimum in January-February and maximum in July-August
- Critical habitat for animals; e.g., loggerhead sea turtles use as migration pathway

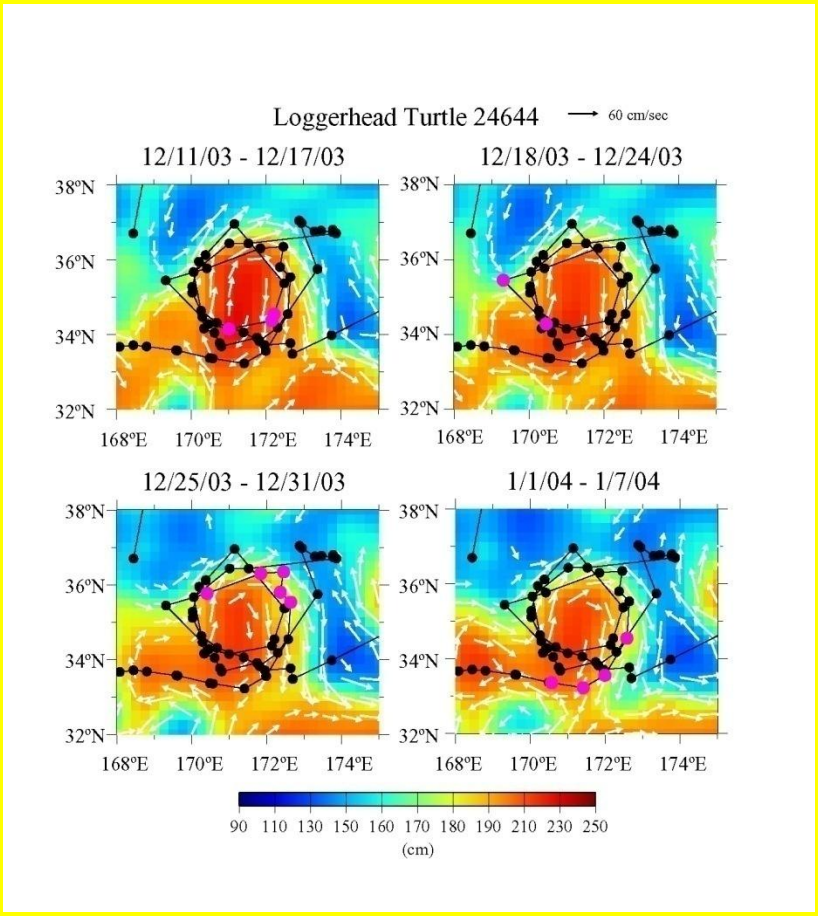


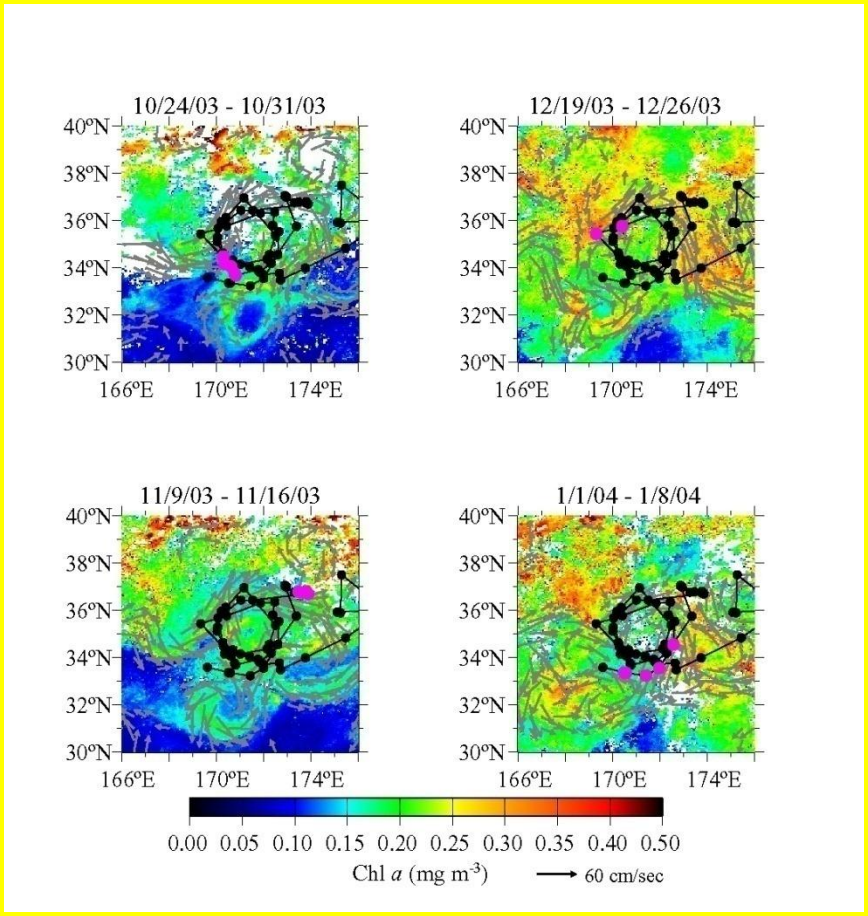


Loggerhead Turtle Movements, Swordfish Catch and Ocean Color



Loggerhead turtles response to mesoscale oceanographic features

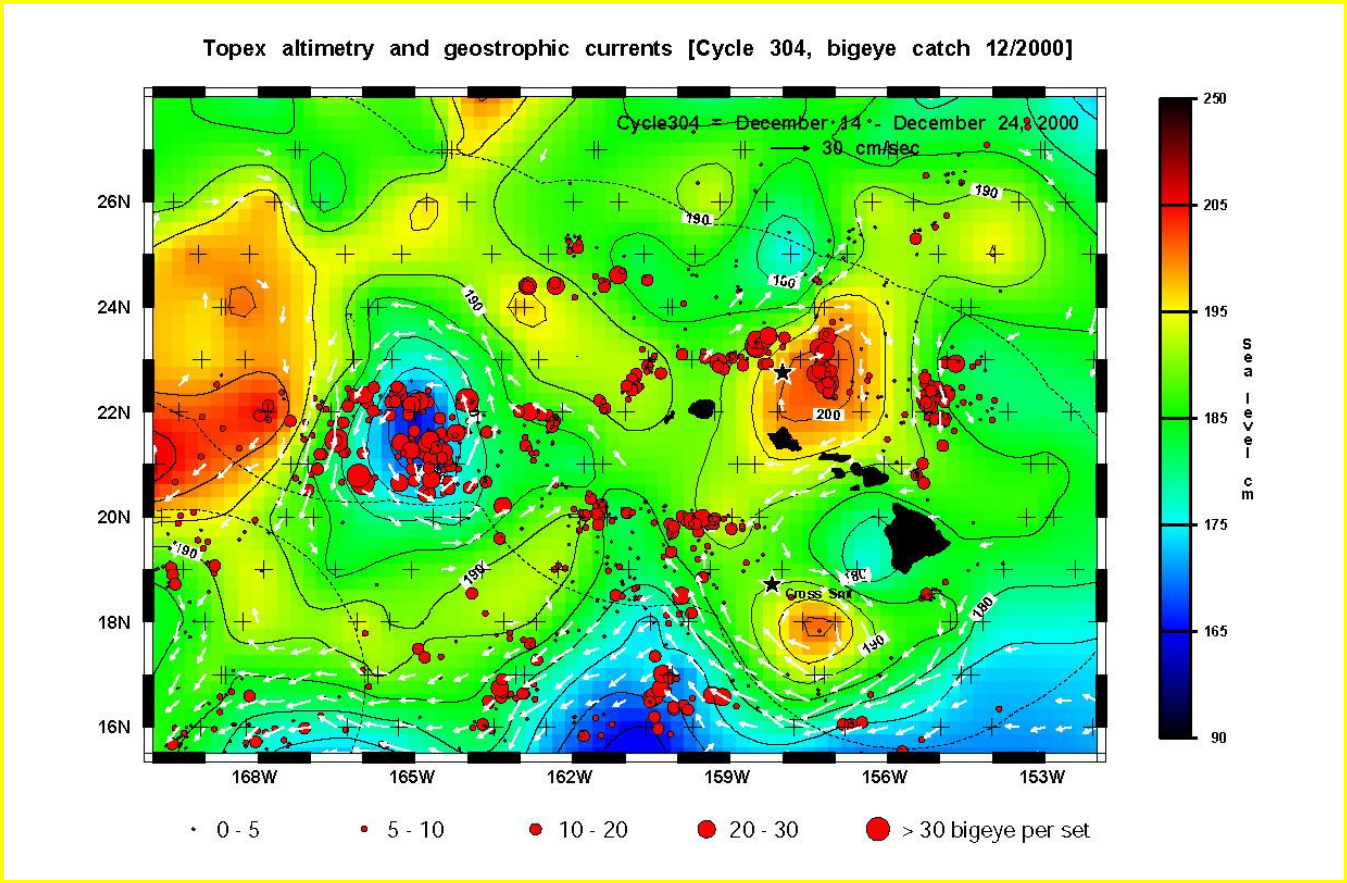




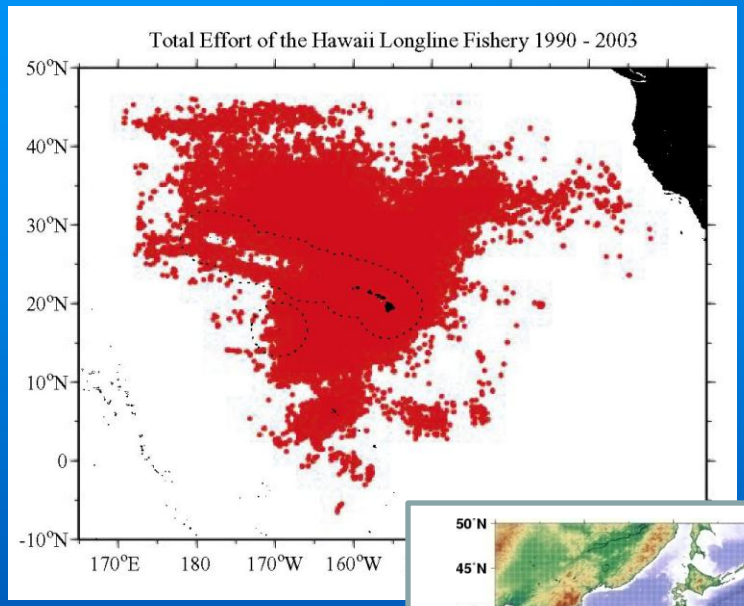
Sea Turtles' Diet

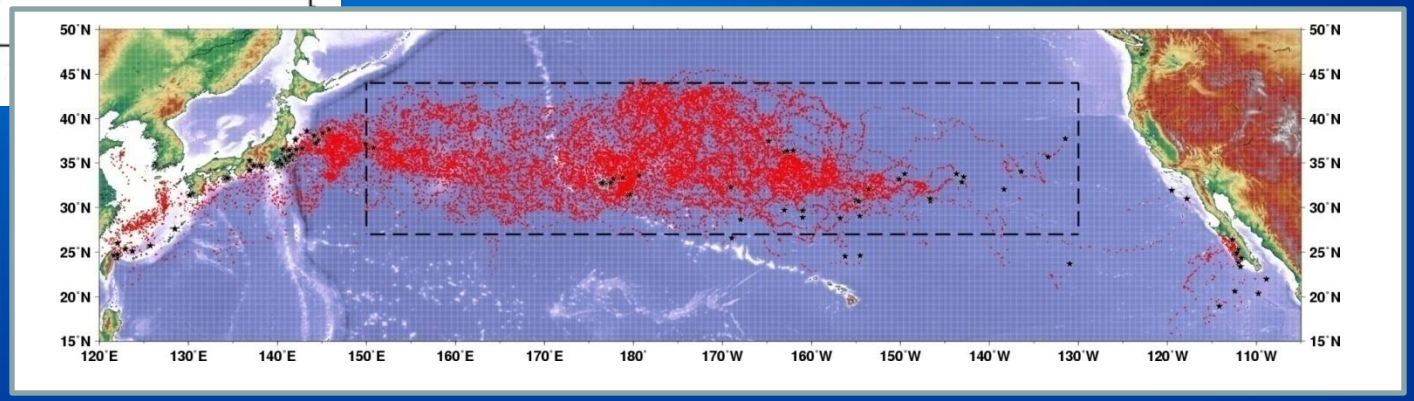
- **Loggerhead diet dominated by surface prey: *Vellela vellela*, *Janthina* sp., *Planes cyaneus*, gooseneck barnacles**
- **Olive ridley and leatherbacks diet dominated by subsurface prey: pyrosomes and salps**

Longline catches of bigeye tuna and Topex altimetry

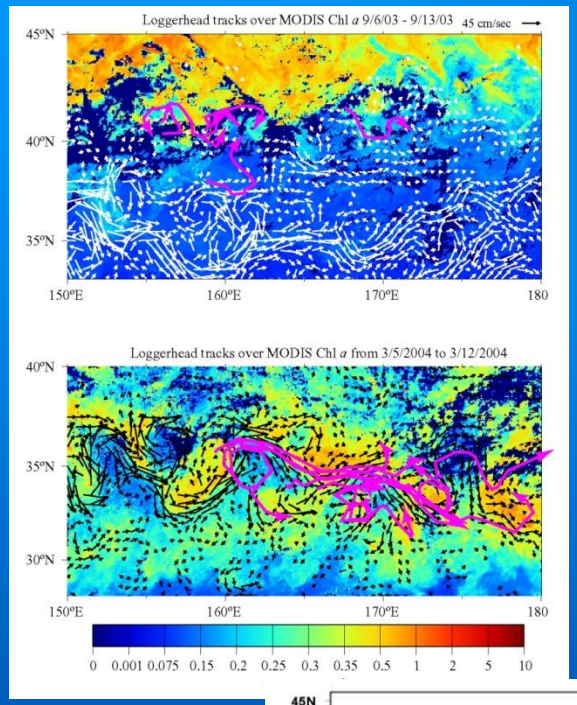


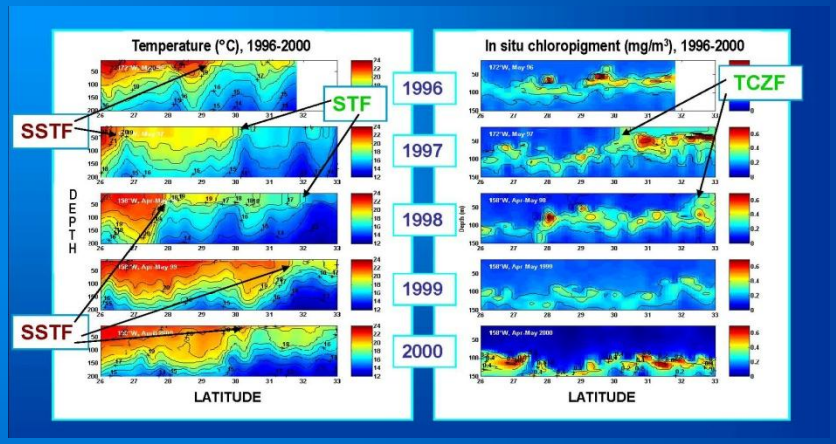
Fishery Observer Data & Aggregated Loggerhead Turtle track data

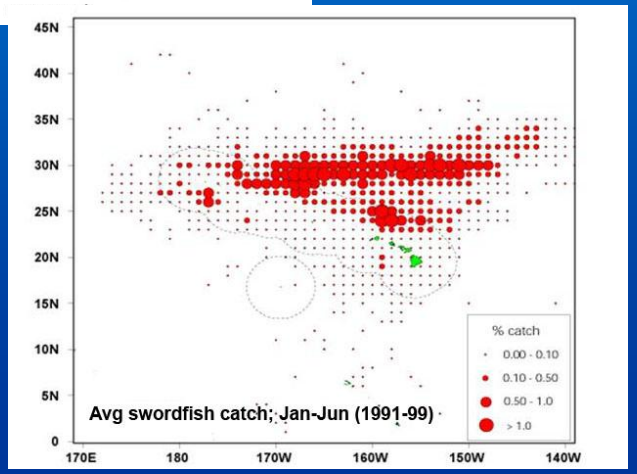


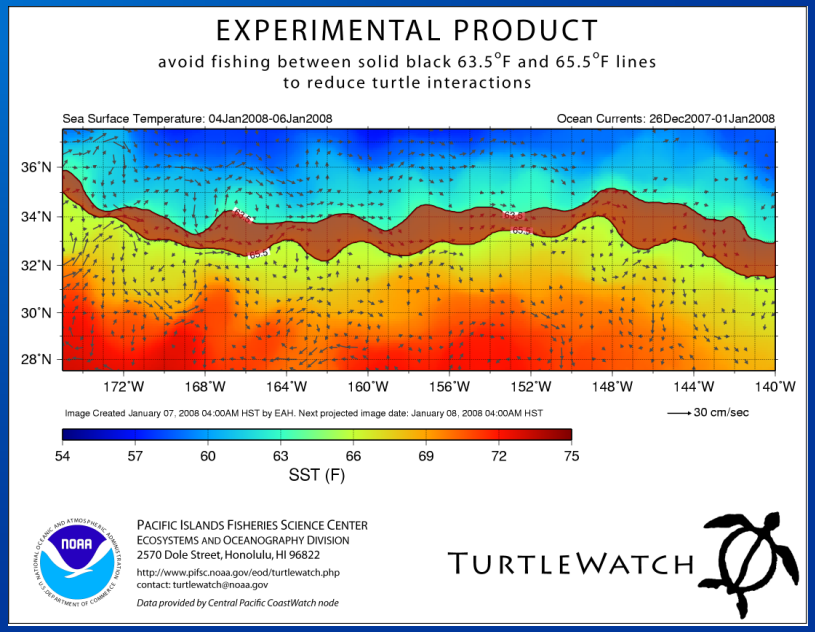


Subtropical Front Ecosystem and "Turtlewatch"

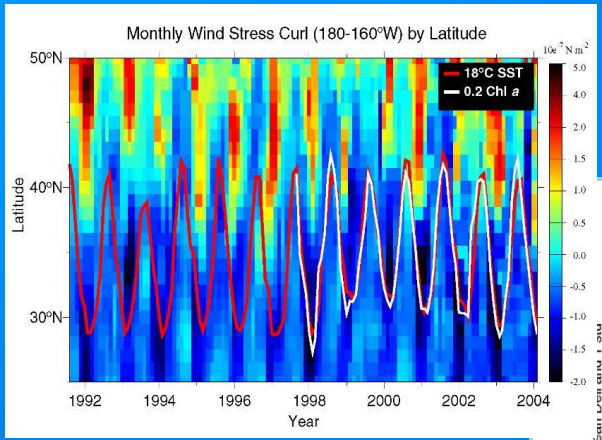


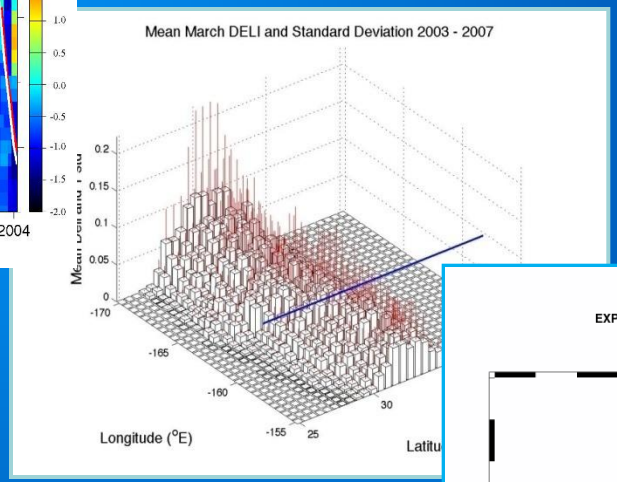


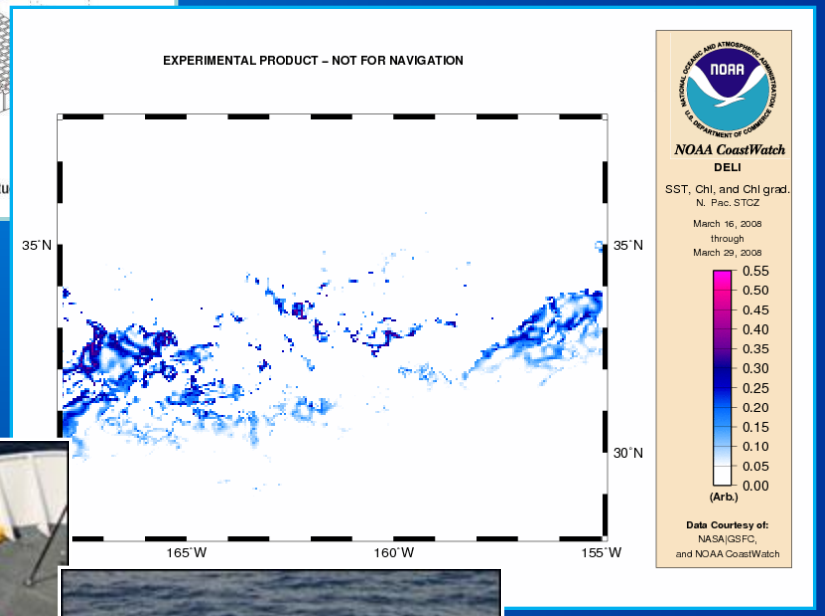




DELI (Debris Estimated Likelihood Index) Maps, Ghostnets, & AUVs







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Marine Pollution Bulletin 54 (2007) 1207–1211

MARINE POLLUTION BULLETIN

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Marine debris collects within the North Pacific Subtropical Convergence Zone

William G. Pichel [a], James H. Churnside [b,*], Timothy S. Veenstra [c], David G. Foley [d,e], Karen S. Friedman [a], Russell E. Brainard [f], Jeremy B. Nicoll [g], Quanan Zheng [h], Pablo Clemente-Colón [a]

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[h] Department of Atmospheric and Oceanic Science, University of Maryland, College Park, MD 20742, USA

Abstract

Floating marine debris, particularly derelict fishing gear, is a hazard to fish, marine mammals, turtles, sea birds, coral reefs, and even human activities. To ameliorate the economic and environmental impact of marine debris, we need to efficiently locate and retrieve dangerous debris at sea. Guided by satellite-derived information, we made four flights north of Hawaii in March and April 2005. During these aerial surveys, we observed over 1800 individual pieces of debris, including 122 derelict fishing nets. The largest debris concentrations were found just north of the North Pacific Transition Zone Chlorophyll Front (TZCF) within the North Pacific Subtropical Convergence Zone (STCZ). Debris densities were significantly correlated with sea-surface temperature (SST), chlorophyll- a concentration (Chl a), and the gradient of Chl a. A Debris Estimated Likelihood Index (DELI) was developed to predict where high concentrations of debris would be most likely in the North Pacific during spring and early summer.

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Keywords: Marine debris; Derelict fishing gear; North Pacific Subtropical Convergence Zone

1. Introduction

The increased use off ong-lasting synthetic materials since the 1950s has led to increases in the negative effects of marine debris. Plastic particles are ingested by sea birds and small marine animals instead off ood (Carr, 1987). Fish, birds, sea turtles, and marine mammals are entangled and killed in derelict nets (also referred to as "ghostnets") (Laist, 1987). Ships and submersibles can be trapped by the fouling of nets and lines in propellers or damaged by collision with bulky floating debris. Nets physically damage coral reef substrates while they continue to entangle and kill reef animals (Donohue et al., 2001). Between 1996 and 2006, NOAA recovered a total of 511 metric tons of fishing gear from the reefs of the Northwest Hawaiian Island Marine National Monument (NWHI-MNM), one of the largest marine conservation areas in the world. A recent report estimates an annual accumulation rate of approximately 52 metric tons of derelict fishing gear (Dameron et al., 2006). The economic loss of commercial

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Closing comments

- Oceanic fronts are “hot spots” and generally highly dynamic areas where considerable transfer of energy occurs.
- These regions concentrate biotic as well as abiotic “particles” on varied scales ….
- and understanding these systems are vital to for quantitative assessments (e.g., population assessments).

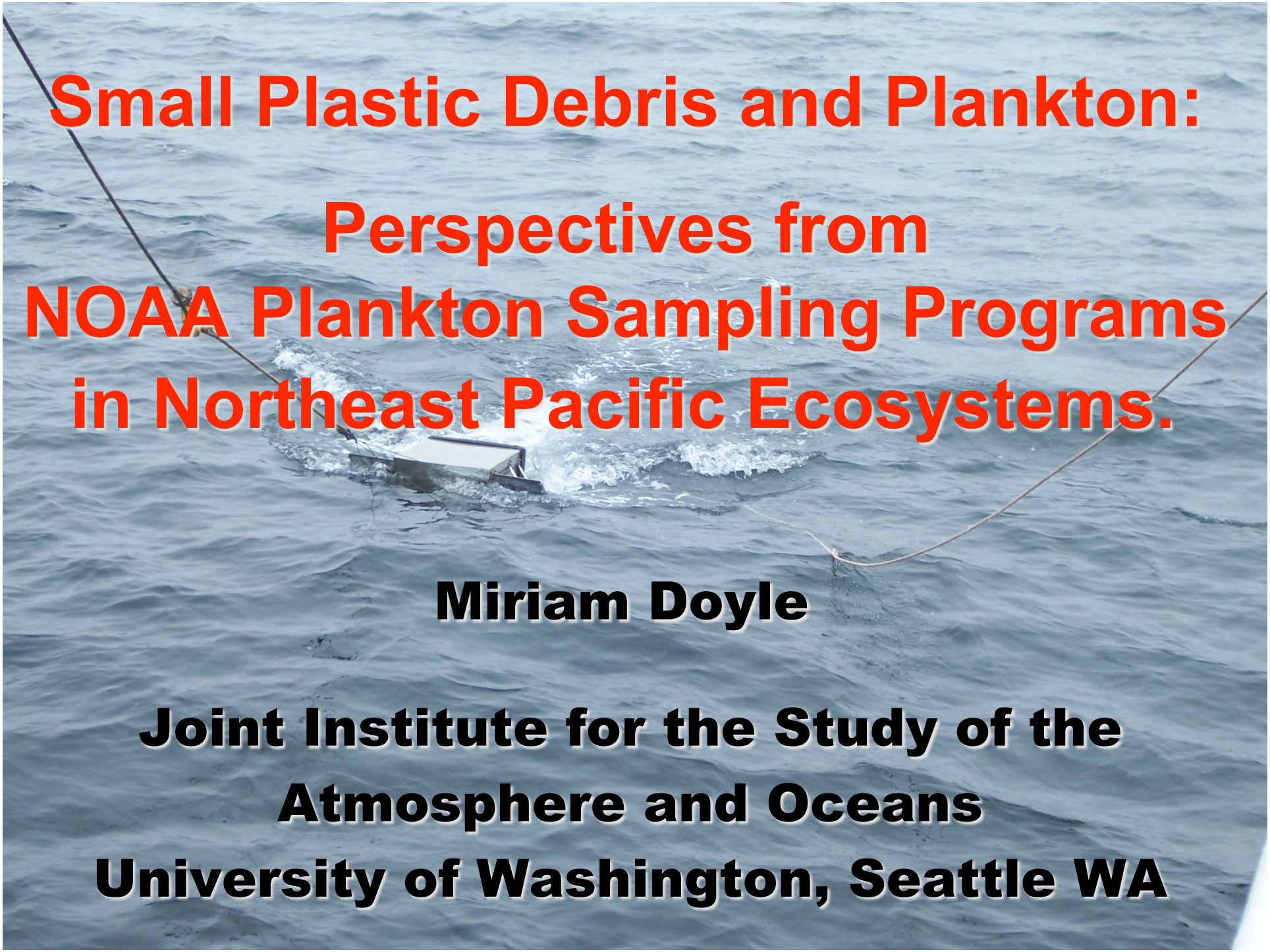
Small Plastic Debris and Plankton: Perspectives from NOAA Plankton Sampling Programs in Northeast Pacific Ecosystems

Dr. Miriam Doyle, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA

Abstract: The purpose of this study was to examine the incidence of small particles of plastic in plankton samples collected in Northeast Pacific ecosystems, and to contribute to the development of a standardized protocol for future research into the occurrence and effect of small plastic debris in marine pelagic ecosystems. Zooplankton samples were collected in conjunction with the National Oceanic and Atmospheric Administration's (NOAA) ongoing ecosystem surveys in the Northeast Pacific, during four research cruises off California in spring, summer and fall of 2006, and in January of 2007, and two research cruises in the Southeast Bering Sea in the spring and fall of 2006. Neuston samples were collected during all cruises, and sub-surface samples during the four cruises off California. A total of 593 plankton samples from these research cruises were processed for debris particles. Results from this study indicate that tiny amounts of small plastic debris are present primarily in surface waters of the California Current and Southeast Bering Sea coastal ecosystems. The mean standardized quantity of plastic debris, expressed as mass (mg) and numbers of particles per meter cubed, was very low overall for both sampling areas and all cruises (<1 mg/ m^3, and <0.2 particles/m^3, respectively) but spatial and temporal variability was apparent within the range of values recorded. The plastic particles were assigned to three plastic product types: product fragments, fishing net and line fibers, and industrial pellets; and five size categories: <1 mm, 1-2.5 mm, 2.5-5 mm, 5-10 mm, and >10 mm. Product fragments accounted for the majority of the particles, and most were less than 2.5 mm in size. Although the quantity of plastic particles was extremely low, their ubiquity in the plankton samples and predominance of particles <2.5 mm, implies persistence in these pelagic ecosystems as a result of continuous breakdown from larger plastic debris fragments, and widespread distribution by ocean currents. The estimated biomass of zooplankton was many orders of magnitude higher than the mass of plastic particles, both for average cruise values and among individual samples, implying minimal interaction between small plastic debris and zooplankton organisms in these regions.

This project was supported by a grant from the National Fish and Wildlife Foundation in partnership with the National Oceanic and Atmospheric Administration's Marine Debris Program, and the American Chemistry Council.

Miriam Doyle, PhD, has worked for 17 years at the Alaska Fisheries Science Center in Seattle, USA, on a variety of research projects in the field of early life history ecology of Northeast Pacific fishes, prior to which she studied the ecology of early life stages of fish species in the plankton of the Northeast Atlantic. Through the JISAO Institute at the University of Washington, she works with NOAA scientists at the Alaska Fisheries Science Center and the Pacific Marine Environmental Laboratory to understand the influence of climate and ocean processes on fluctuations in Alaska fish populations.



Small Plastic Debris and Plankton:

Perspectives from NOAA Plankton Sampling Programs in Northeast Pacific Ecosystems.

Miriam Doyle

Joint Institute for the Study of the Atmosphere and Oceans
University of Washington, Seattle WA

My Background:

Fisheries Oceanography
Early Life History of Fish
Plankton Sampling Programs

Disclaimer

Not speaking for NOAA or UW,
Independent Contractor
for this study

PROJECT BACKGROUND

Marine Debris Research

Gap in knowledge regarding abundance and distribution of plastic micro-debris in coastal and ocean waters

Interest from American Chemistry Council in assessment of Plastic Debris in US coastal and ocean waters

Opportunity with NOAA plankton sampling programs

Funding

NOAA Marine Debris Program through National Fish and Wildlife Foundation

Matching funds from ACC

Pilot Study of Plastic Debris in the planktonic environment

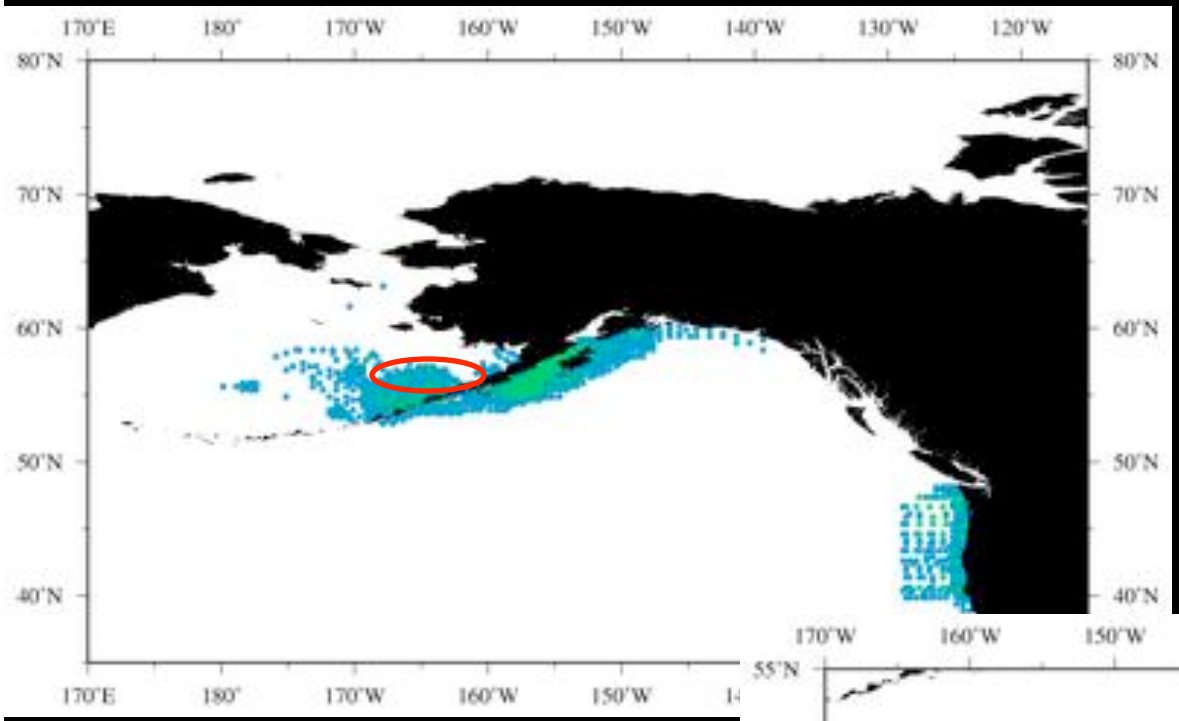
Groups involved in Study:

ACC and Sheavly Consultants –
Project Management

NOAA National Marine Fisheries Service –
Provision of Samples and
Plankton Research Expertise

AFSC: Bering Sea samples and data

SWFSC: CalCOFI samples and data, sorting of plankton samples, removal of inorganic debris, measurement of zooplankton biomass

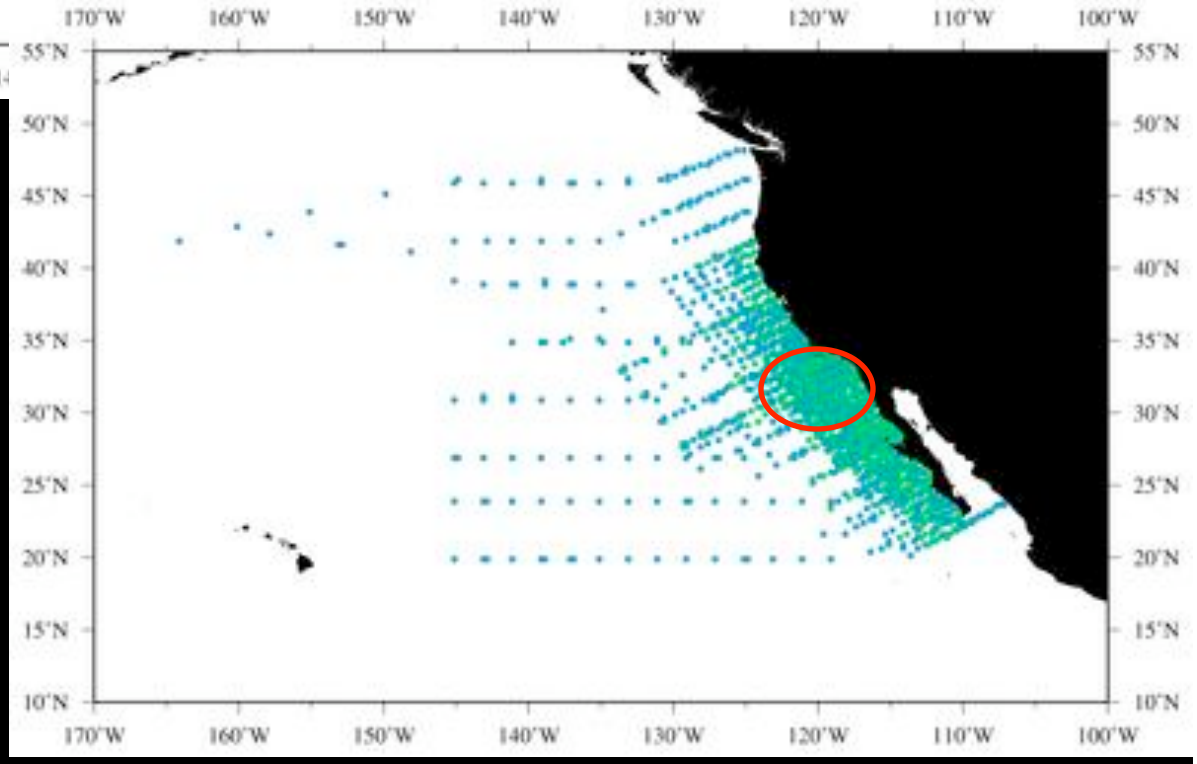


EcoFOCI

Ecosystem Fisheries Oceanography Coordinated Investigations

CalCOFI

California Cooperative Oceanic and Fisheries Investigations



Plankton 101
A sense of scale

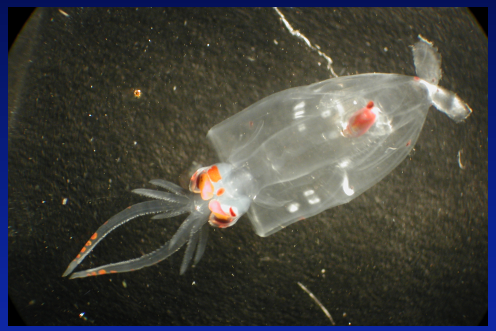
- **Phytoplankton - microscopic plants unicellular oganisms**

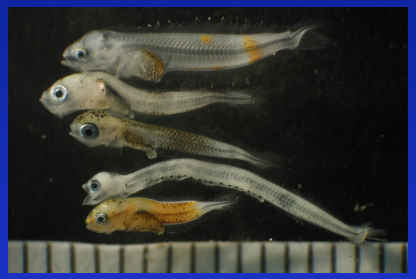
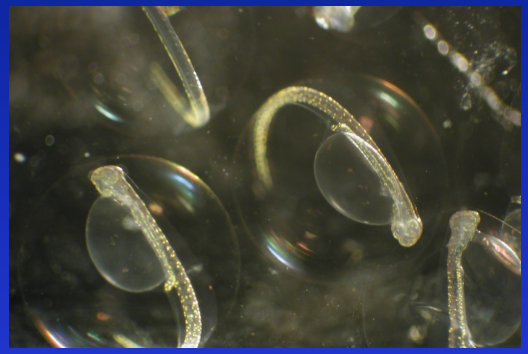
- **Zooplankton - small animals that eat phytoplankton and other zooplankton: micro- (<0.2 mm), meso- (0.2-0.5 mm), *macrozooplankton (>0.5 mm)**

- ***Ichthyoplankton - fish eggs and larvae**

* plastic ingestion potential – likely organisms of interest?

Macrozooplankton: Invertebrates and Fish



NEUSTON

Unique biotope at ocean surface

Planktonic organisms unique to this layer and organisms that migrate into this zone on a diel basis

Neustonic organisms most likely to be impacted by floating debris particles

METHODOLOGY

Plankton Sampling and Processing

Standard scientific techniques

6 sampling cruises:

2 Bering Sea, 4 CalCOFI region

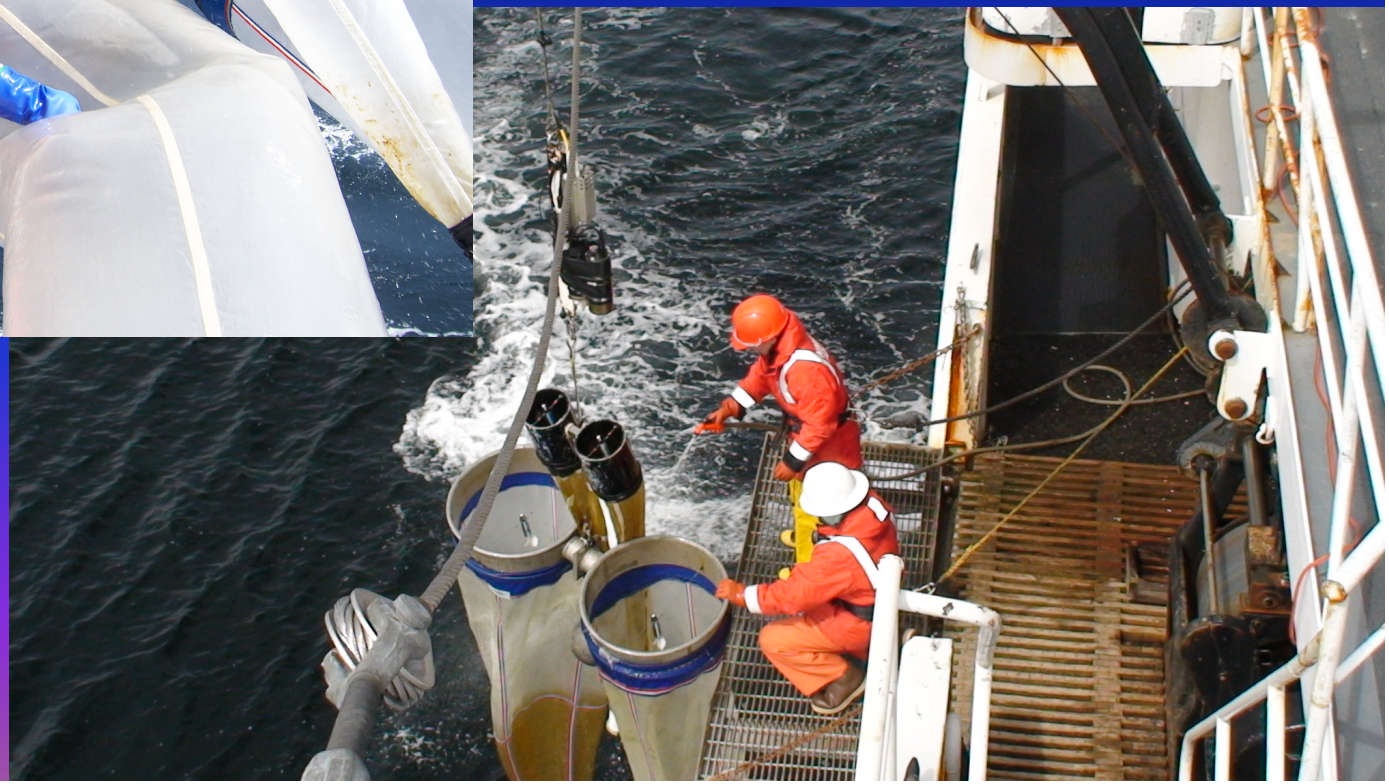
Total of 593 samples processed

Debris Analysis

Independent Analytical Lab

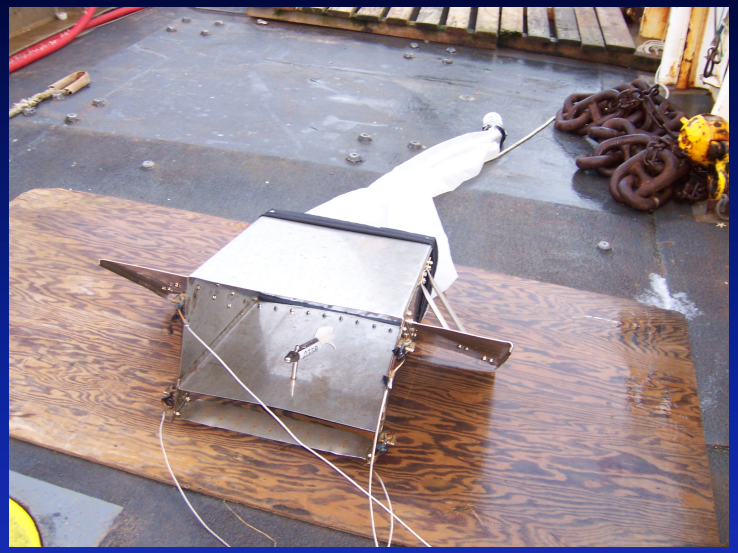
Bongo Nets – SubSurface Tows

0.505 mm mesh

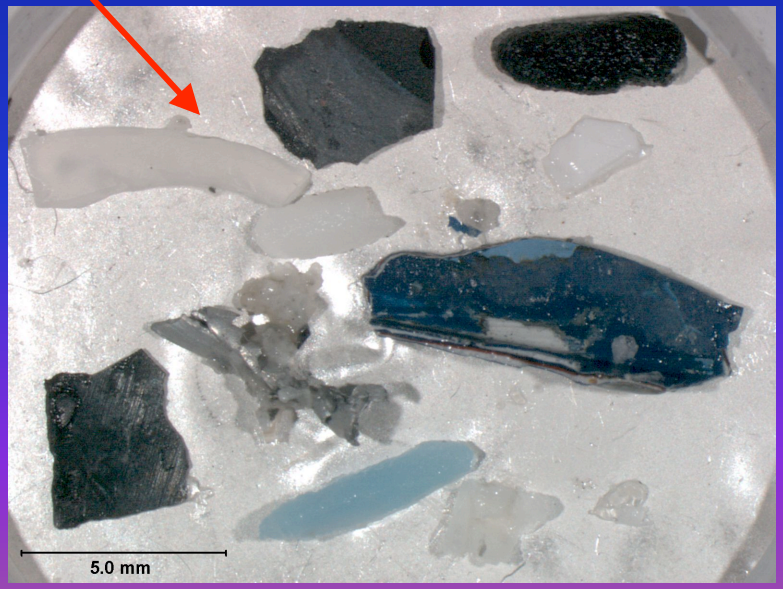


Neuston Nets – Surface Tows

0.505 mm mesh



Processing



Zooplankton Biomass

Displacement Volume:

Liquid volume displaced by the Wet Plankton

Dry Mass:

Plankton dry mass related in a nonlinear way to wet mass. Displacement volume can be converted to dry mass.

Debris Analysis

Independent Lab: Impact Analytical

Non-Plastic Debris:

Paint Chips and Metal Shavings

(include contaminants from ship)

Pebbles and Shell Fragments

Plastic Debris:

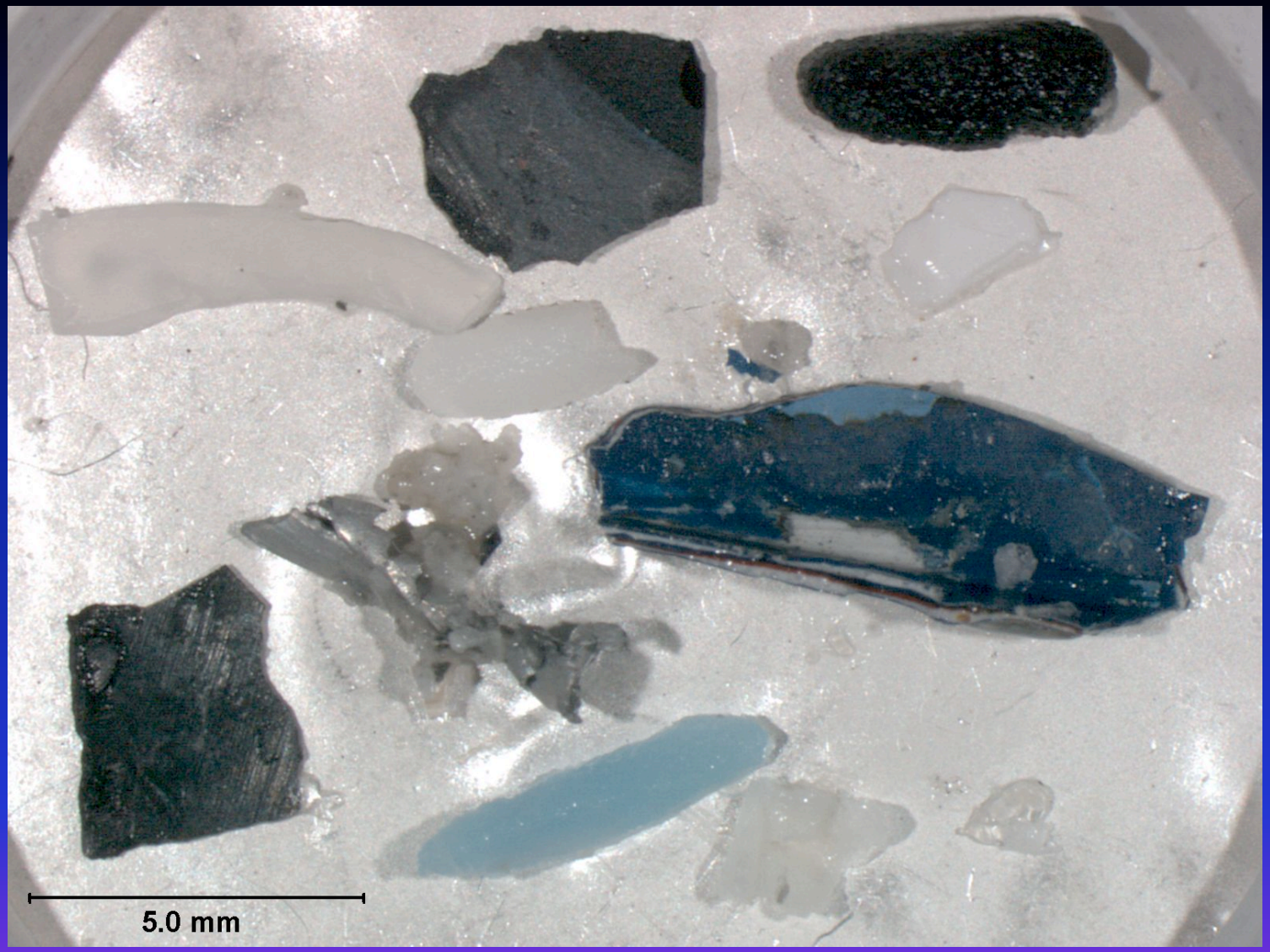
Product Fragments

Fishing Net and Line Fibers

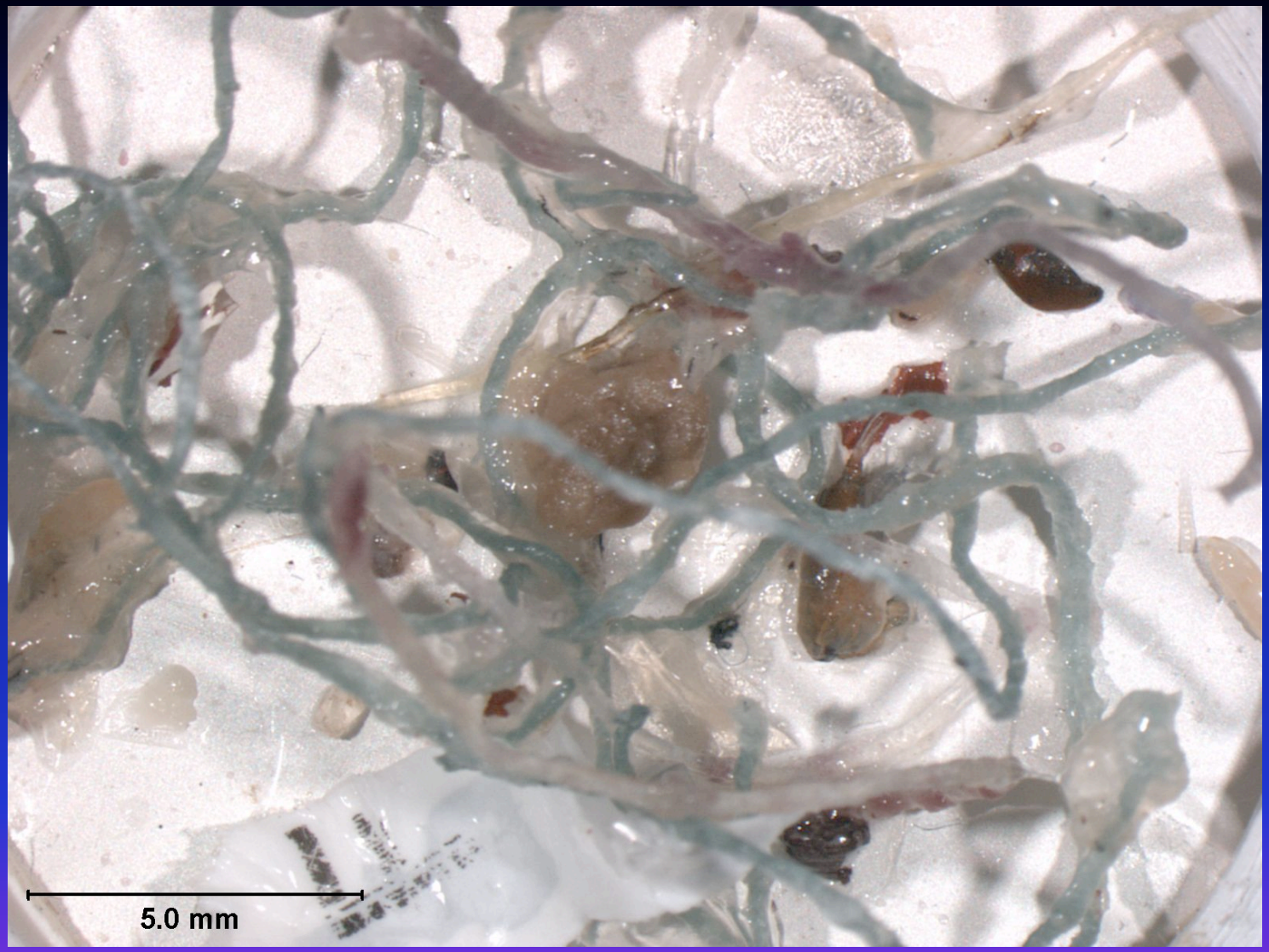
Raw Material Plastic Resin Pellets

S07-2252 Plastic strands, chip fragment, film

S07-2286 Plastic pellets and Polystyrene foam beads



S07-2330 Blue and white plastic chips, metal shavings and paint chips



S07-2546 Fishing net/line strands and plastic film

S07-2558 Multiple plastic forms (incl. plastic foam), paint chips

Each Sample:

- Sorted into Non-Plastic and Plastic
- Plastic assigned to three types:
  - product fragments
  - fishing net and line fibers
  - industrial pellets
- Dry Weight total plastic
- Particle counts for each type
- Particles assigned to 5 size categories:

<1 mm, 1-2.5 mm, 2-5.5 mm, 5-10 mm, >10 mm

DEBRIS in the Plankton Samples

SCALE PERSPECTIVE

From 6 cruises/ 593 samples :

Total Debris Weight = 3.82 grams

Non-Plastic Debris Weight = 2.37 grams

Plastic Debris Weight = 1.45 grams

Neuston Samples - Summary Statistics

Cruises:	BS 3MF06	BS 6MF06	CalCOFI 0604	CalCOFI 0607	CalCOFI 0610	CalCOFI 0701
Season	May 06	Sept 06	April 06	July 06	Oct 06	Jan 01
Number of Samples Collected (sub-sampled)	12	10	80	64	66	71(37)
Mean No. Items Debris/m^3	0.26	1.37	0.01	0.18	0.08	0.75
% Samples with Debris	100	90	8.75	91.10	79.71	100
% Samples with Plastic Debris	25	40	8.75	81.25	66.67	83.78
Total Debris Mean Weight (mg/m^3)	0.14	3.19	0.03	0.20	0.15	0.49
Non-Plastic Debris Mean Weight (mg/m^3)	0.10	3.14	0.001	0.093	0.112	0.286
Plastic Debris Mean Weight (mg/m^3)	0.04	0.08	0.024	0.104	0.033	0.209
Plastic as % of Mean Total Debris Weight	27.96	2.47	95.80	52.86	22.57	42.19
Mean Dry Mass Zooplankton (mg/m^3)	48.97	18.81	14.56	17.39	22.47	22.52

SubSurface Samples - Summary Statistics

Cruises:	CalCOFI 0604	CalCOFI 0607	CalCOFI 0610	CalCOFI 0701
Sampling Dates	April 06	July 06	Oct 06	Jan 01
Number of Samples Collected (subsampled)	136	74	75	79(39)
Mean No. Debris Items/m^3	0	0	0	0.0203
% Samples with Debris	0	0	0	72.15
% Samples with Plastic Debris	0	0	0	28.21
Total Debris Mean Weight (mg/m^3)	0	0	0	0.039
Non-Plastic Debris Mean Weight (mg/m^3)	0	0	0	0.025
Plastic Debris Mean Weight (mg/m^3)	0	0	0	0.014
Plastic as % of Mean Total Debris Weight	0	0	0	36.75
Mean Dry Mass Zooplankton (mg/m^3)	188.65	127.69	37.05	52.82

CAUTION

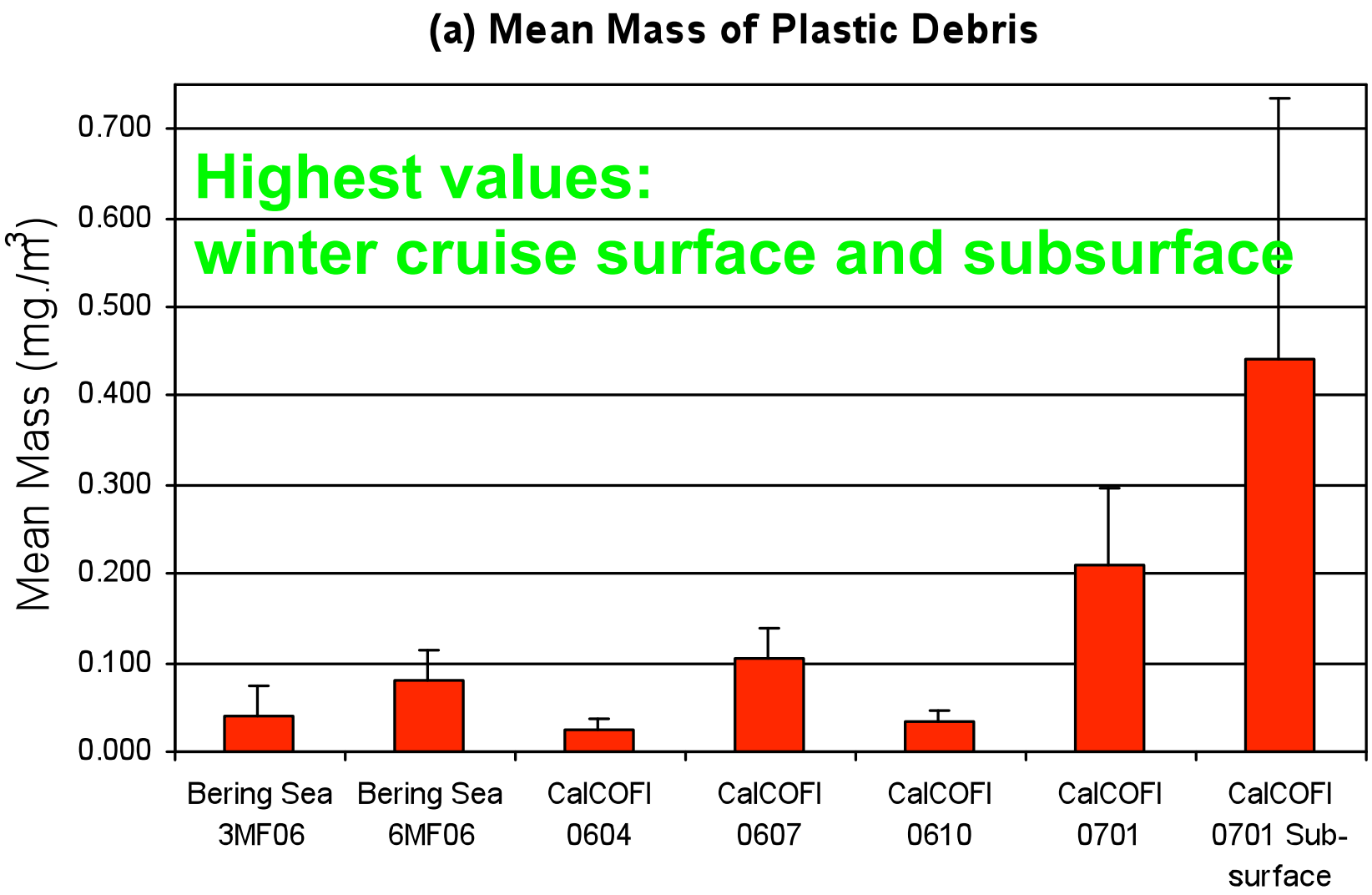
PLASTIC TO PLANKTON WEIGHT RATIO

- Fraught with Error
- Danger of Extrapolation and Misinformation
- Not Scientifically Informative

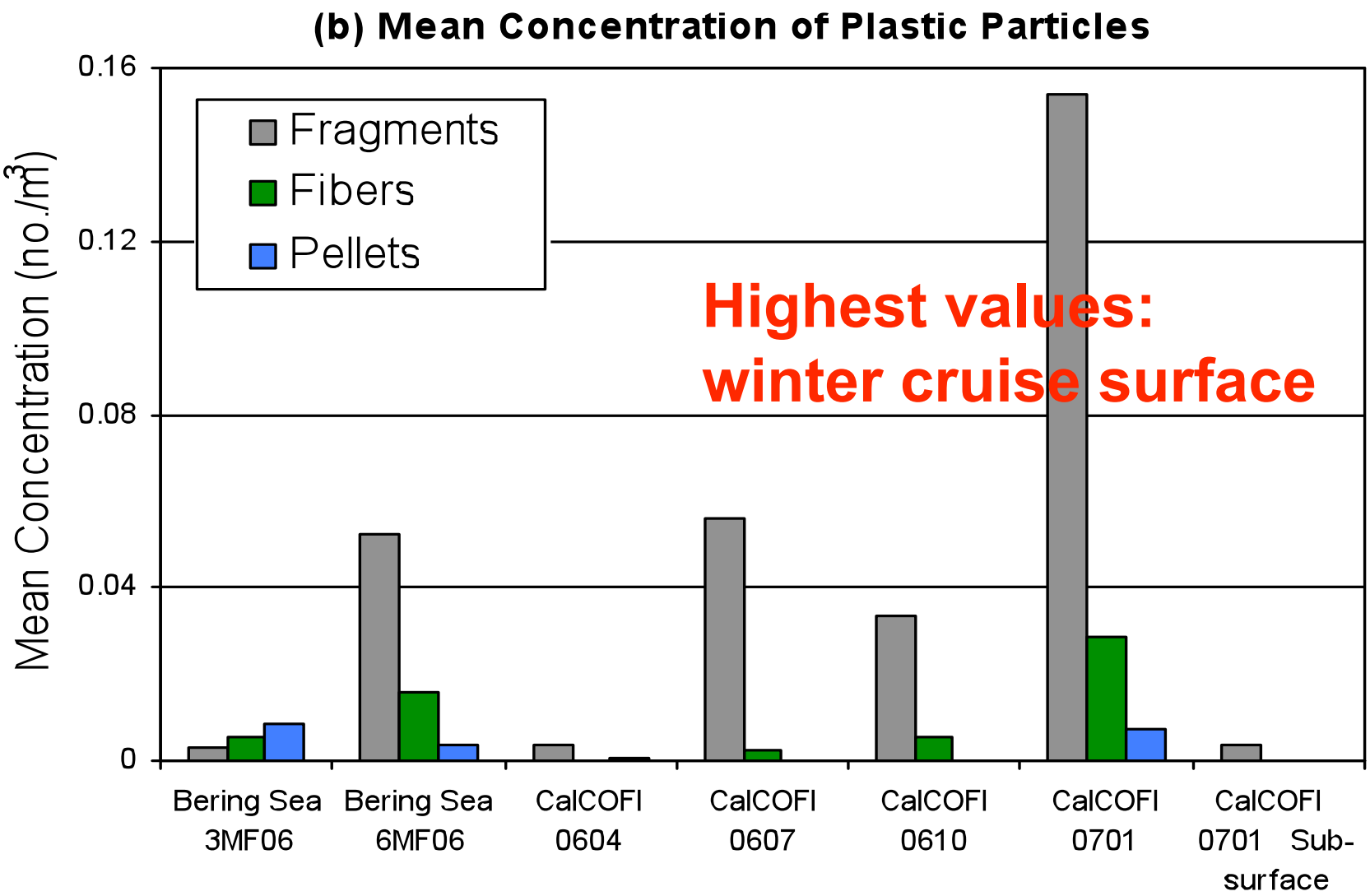
WHY?

- Enormous spatial and temporal variability in plankton production
- Neuston not representative of total plankton (low biomass at surface)
- Selective sampling of plankton nets
- No information on numbers and sizes of debris particles relative to plankton organisms
- No information on potential interaction of debris and plankton

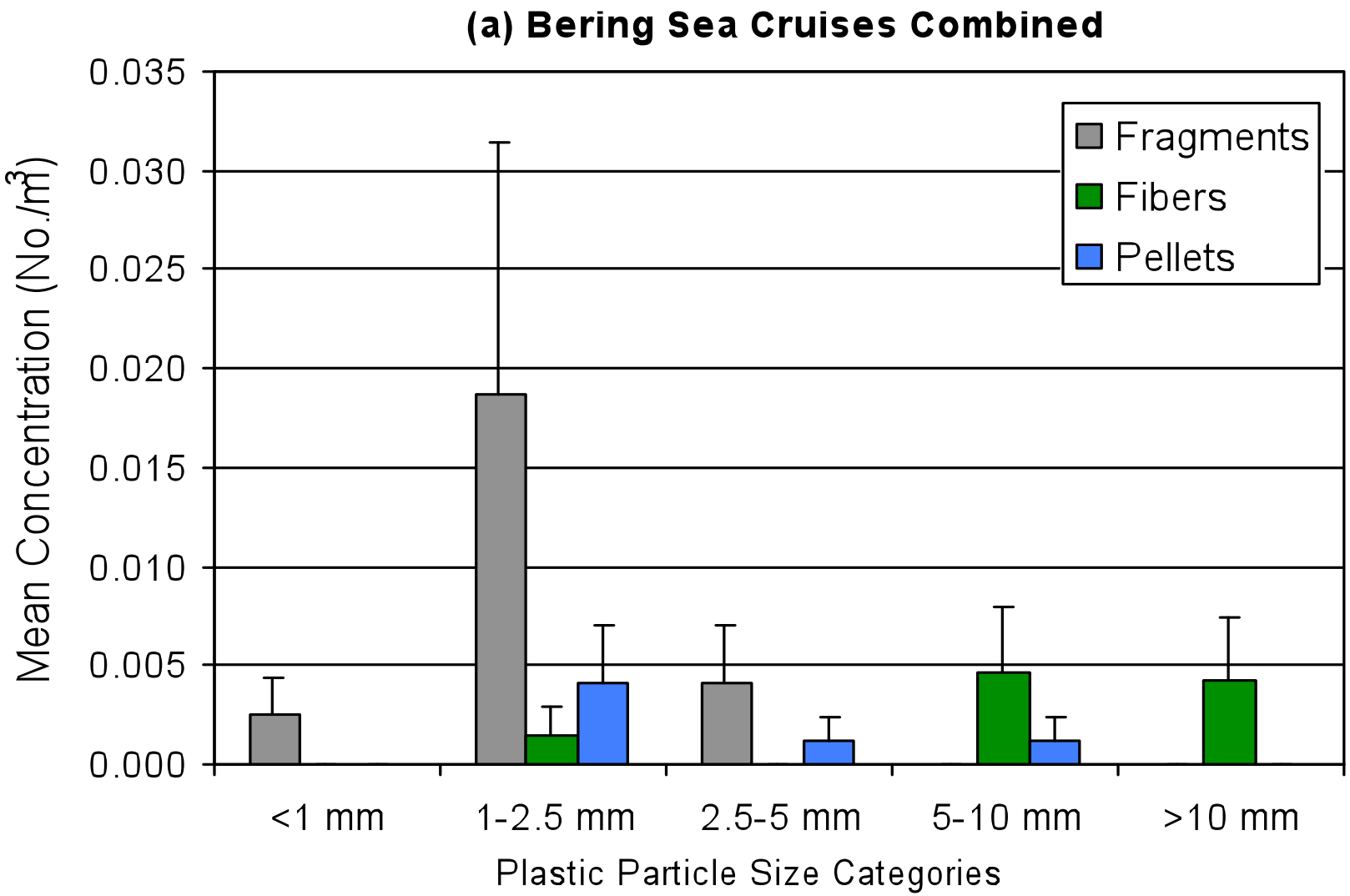
Mass of plastic particles by cruise

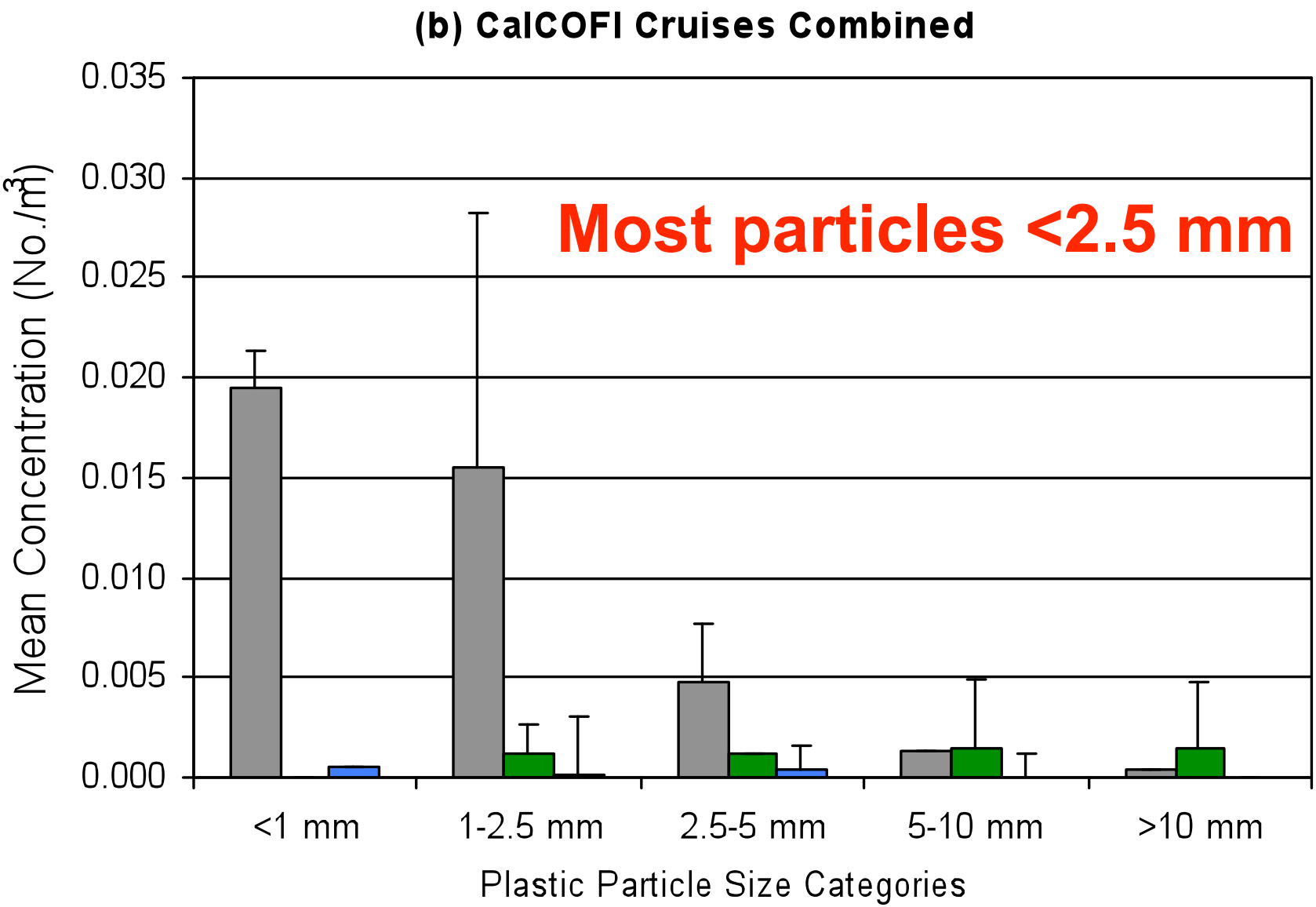


Concentration of plastic particles by cruise

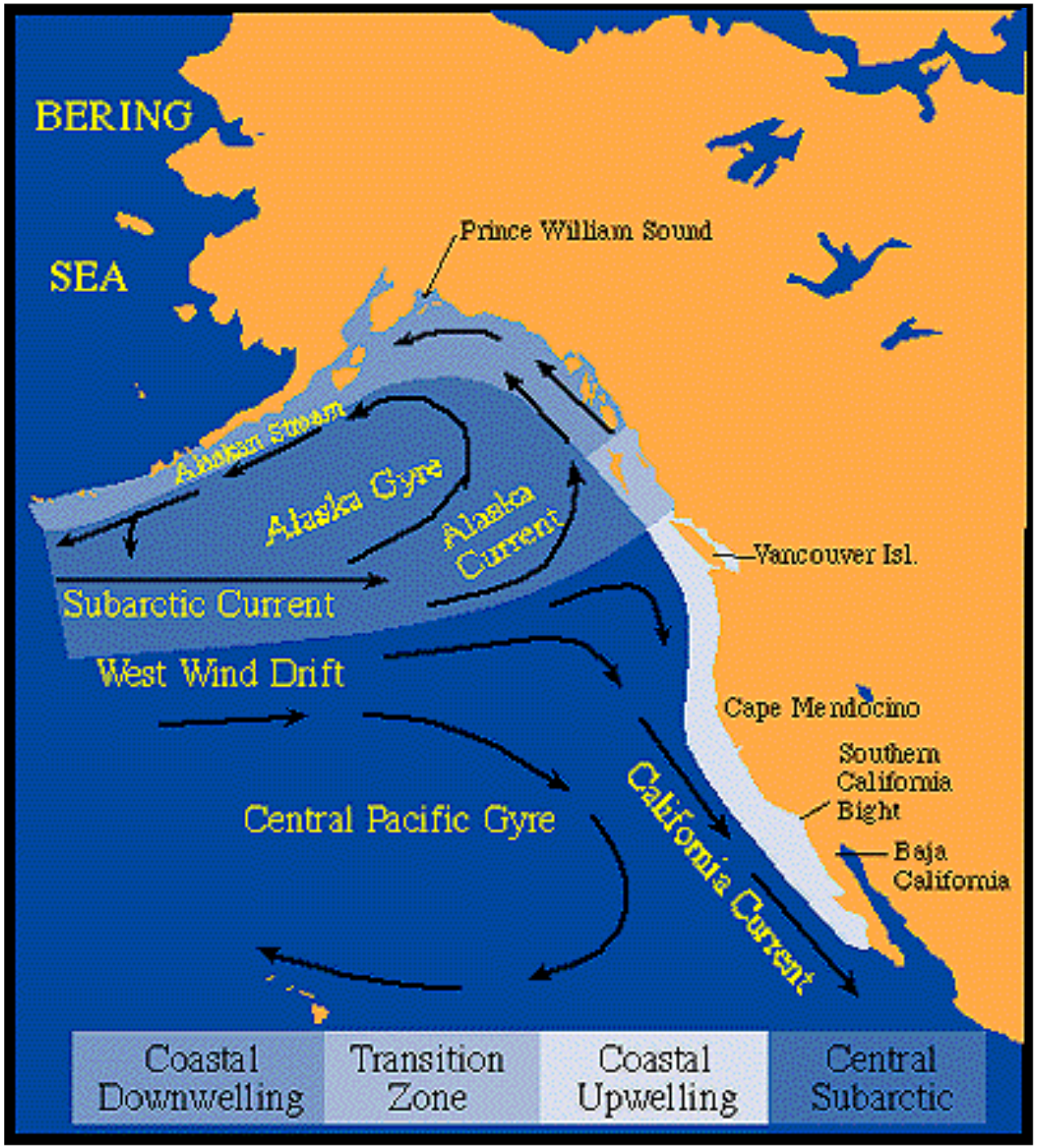


Size Distribution Plastic Particles

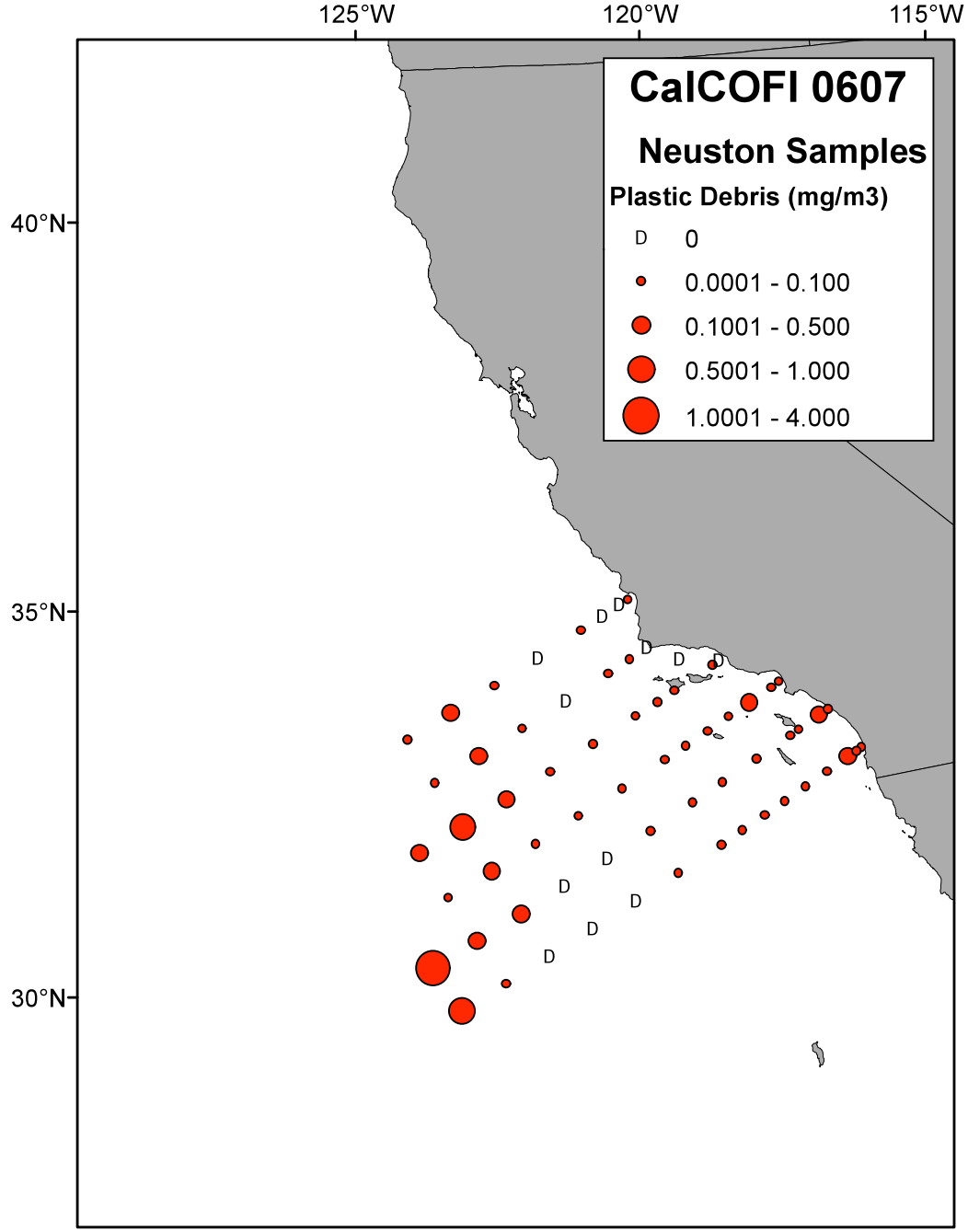



(b) CalCOFI Cruises Combined
Most particles <2.5 mm
Mean Concentration (No./m3)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
<1 mm
1-2.5 mm
2.5-5 mm
5-10 mm
>10 mm
Plastic Particle Size Categories

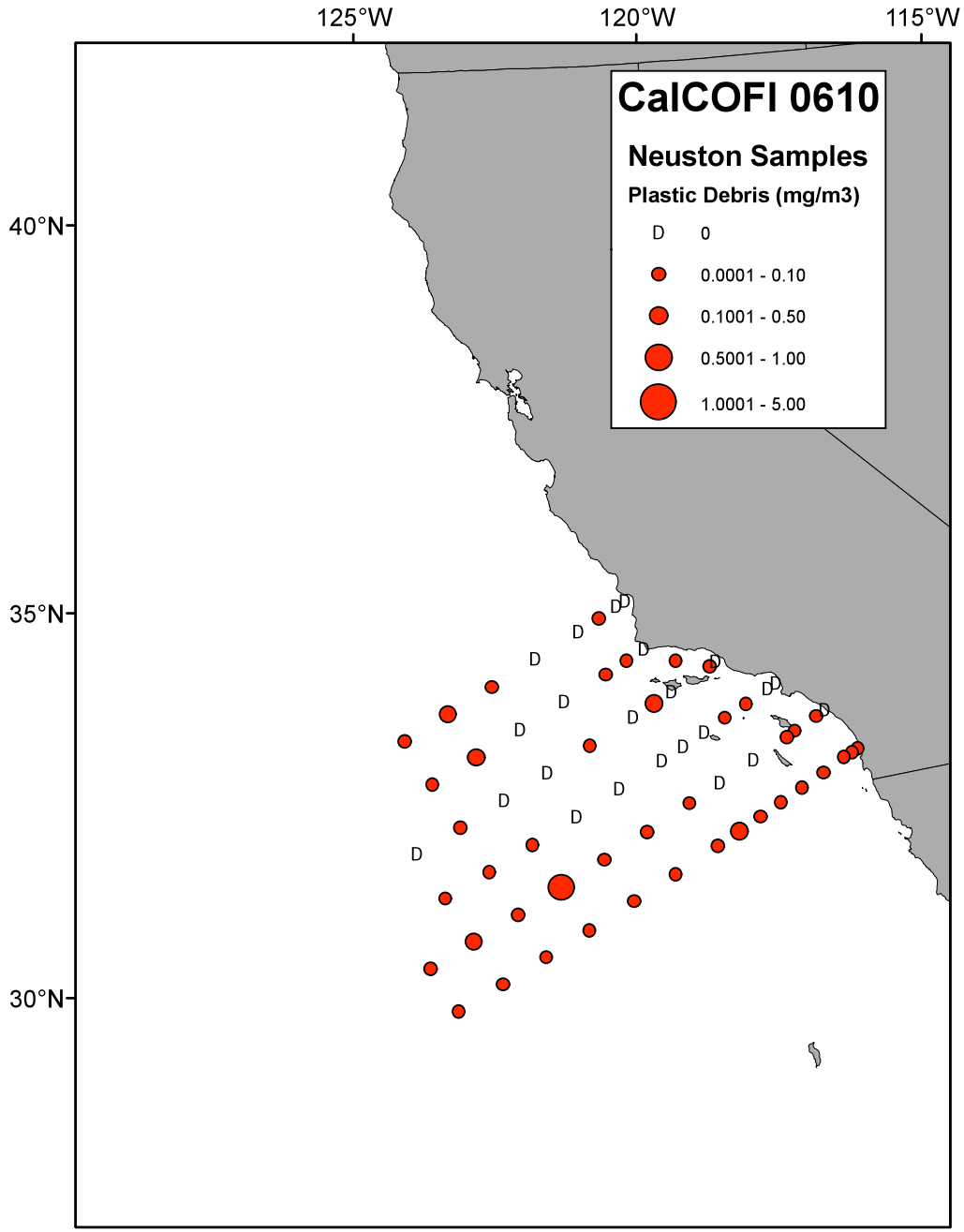
Debris Distribution Patterns



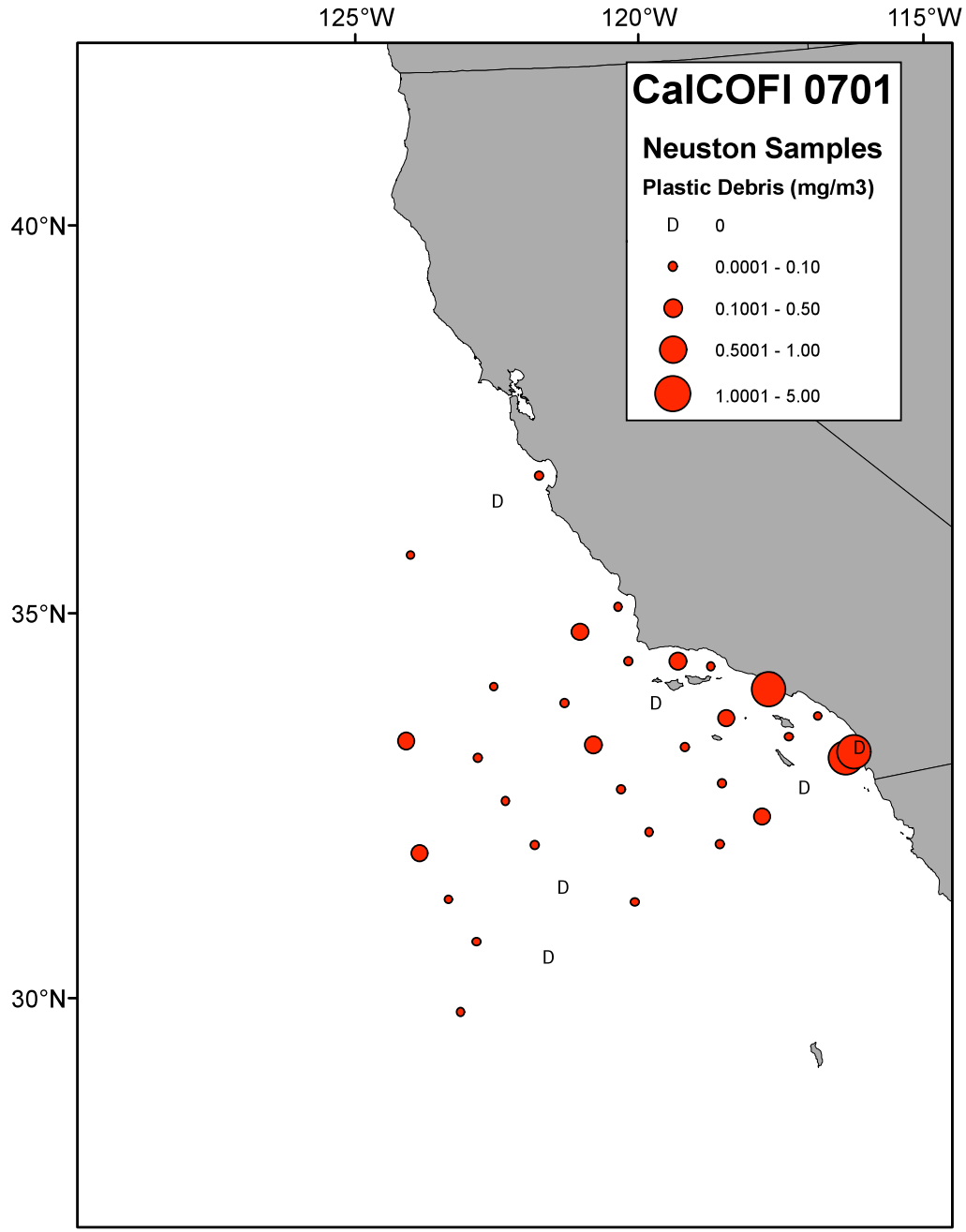
July 2006


125°W
120°W
115°W
40°N
35°N
30°N
CalCOFI 0607
Neuston Samples
Plastic Debris (mg/m3)
D 0
0.0001 - 0.100
0.1001 - 0.500
0.5001 - 1.000
1.0001 - 4.000

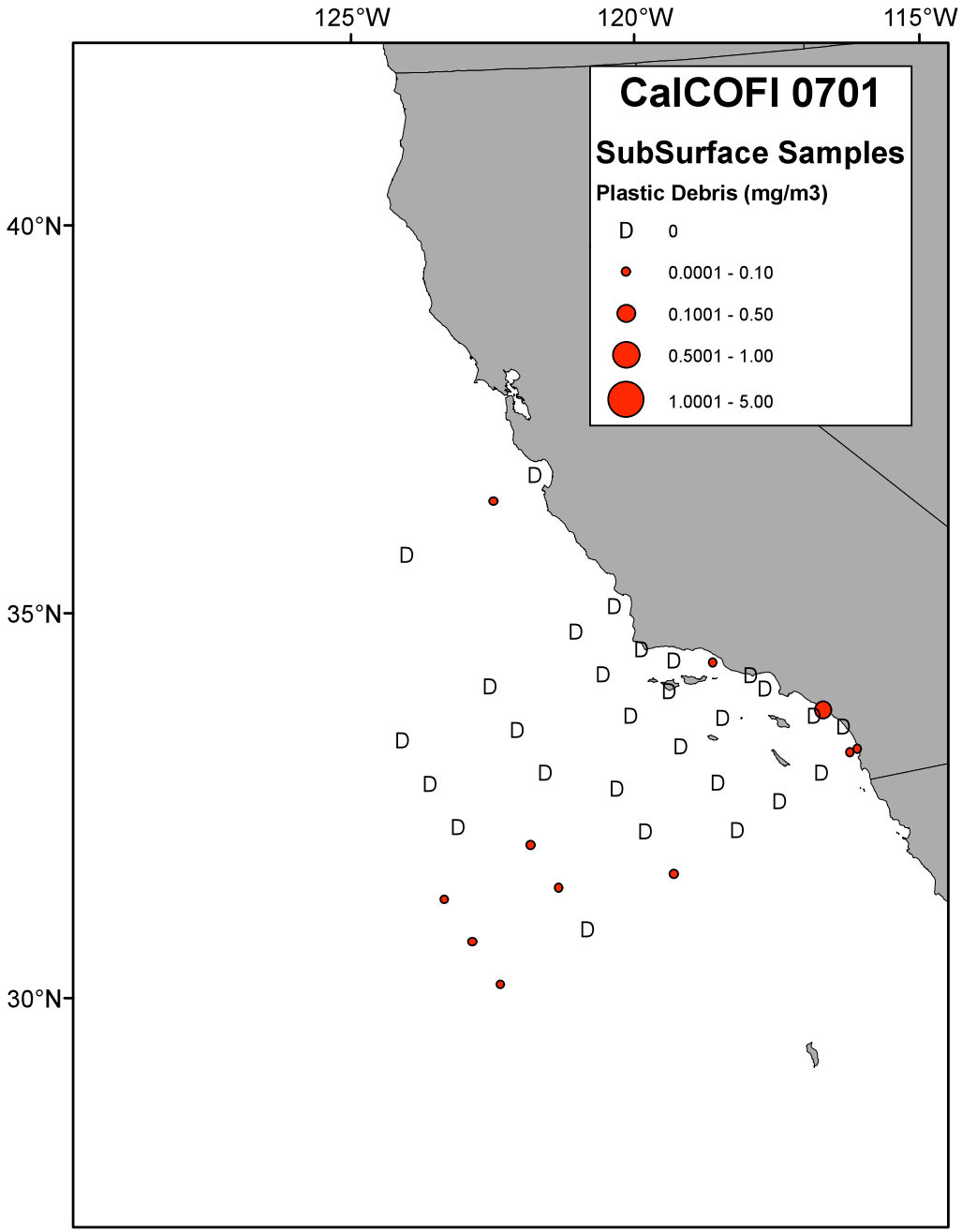
October 2006



January 2007



January 2007 (sub-surface)



Summary of Observations

- Small mass (mg/m^3) and density ($\#/m^3$) plastic particles in BS and CA regions, coastal and deep water
- Plankton Mass>>>Debris Mass
  Plastic (fragments>>fibers>>pellets)
- Debris exclusively at surface, except Jan 07
- Seasonality apparent – likely related to seasonal patterns in circulation
- Size, morphology, distribution of plastic particles imply persistence in marine ecosystems

Questions

Encounter Rates?
Low

Ingestion?
Unlikely

BUT.....

Incidence of debris particles << 0.5 mm ?

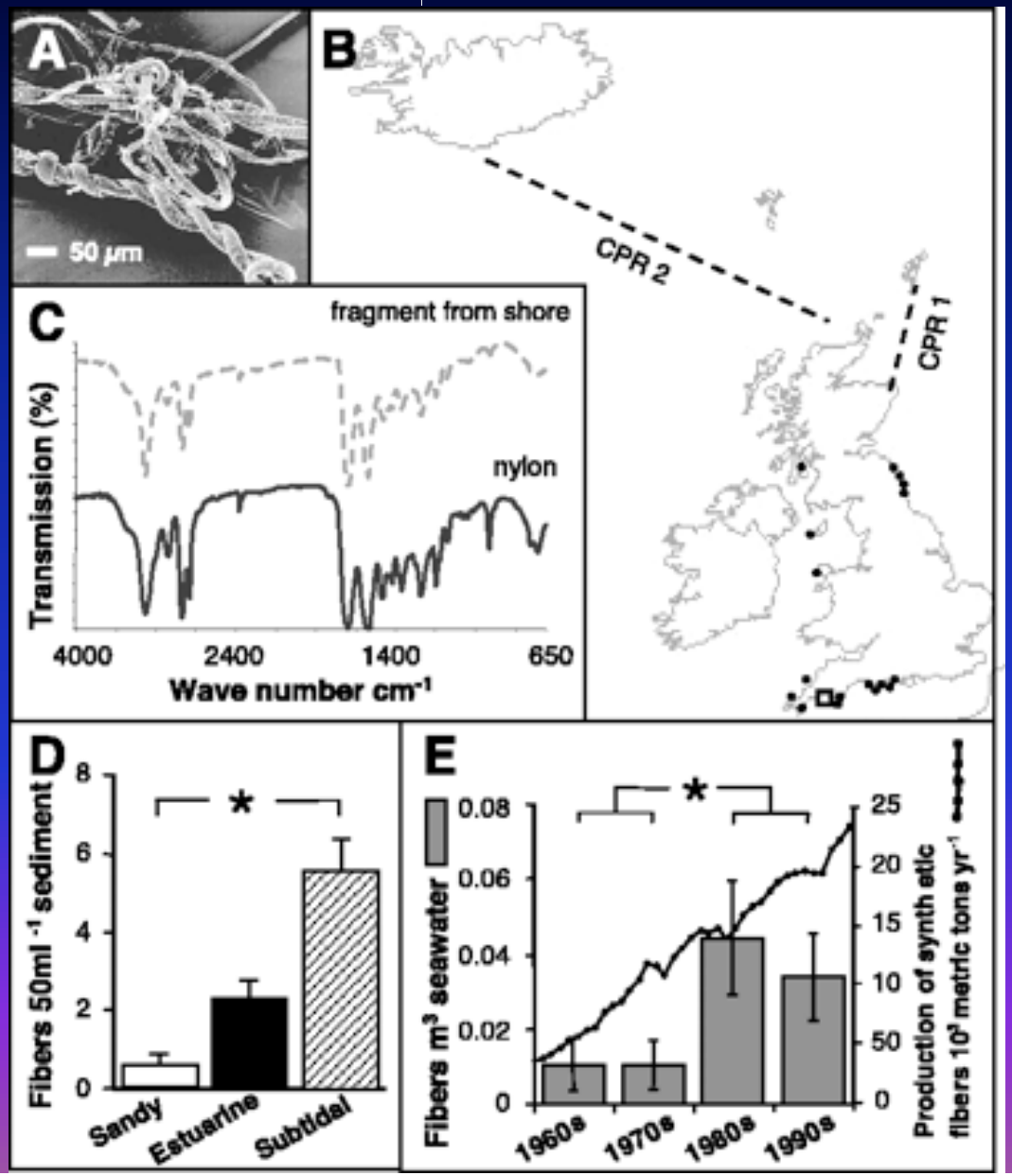
Continuous degradation to smaller and smaller fragments?

Critical concentration of micro-debris particles at which ingestion rates become significant?

(Will vary with prey niche of different organisms)

Chemical contamination? Food-chain concentration?

Decadal Trends?



Thompson et al. 2004

Journal *Science*

Although low, densities of plastic monofilament fiber have increased in North Atlantic CPR samples 1960s-1990s

Similar trend in Pacific Ocean?

RESEARCH RECOMMENDATIONS

- Micro-debris sources and transport dynamics
- Degradation process and end-products
- Debris – Plankton interaction
  - encounter rates/prey niche/behavior
- Incidence of micro-debris ingestion
- Chemical absorption/adsorption/release
- Liason between NOAA Marine Debris Program and NOAA Ecosystem Research Programs

SESSION II: IMPACT OF SMALL PLASTIC DEBRIS ON THE MARINE ENVIRONMENT

FOOLISH FULMARS AND THEIR CONTRIBUTION TO ECOLOGICAL QUALITY

Dr. Jan A. van Franeker, Wageningen IMARES, Den Berg (Texel), THE NETHERLANDS

& the Save the North Sea Fulmar Study Group

Abstract: Indiscriminate foraging enables the Northern Fulmar *(Fulmarus glacialis)* to successfully exploit variable food resources in changing marine environments. But flexibility can be taken too far. Like most tubenosed seabirds, Fulmars ingest a wide variety of man-made litter. Ingested plastics resist digestion and mechanical breakdown in the stomach and accumulate over time. Unlike gulls, Fulmars normally do not regurgitate indigested stomach contents and need to 'process' them slowly in the digestive system. Ingested materials sometimes cause direct mortality but more importantly, indirect sublethal effects will occur in almost all individuals in many populations. However, the accumulated plastics also represent a convenient monitoring instrument for the litter situation in the offshore environment. Stomach contents integrate probably up to several weeks of 'sampling' of the marine litter situation in their foraging area.

In 2002 the North Sea Ministerial Conference decided to tackle marine problems through the concept of 'Ecological Quality Objectives (EcoQO's)'. An EcoQO provides a monitoring system as well as a target for 'acceptable ecological quality'. For the marine litter issue, an EcoQO based on the amount of plastic in stomachs of beached Fulmars was selected. The preliminary political target for acceptable ecological quality was worded as *"less than 10% of Fulmars having more than 0.1 gram of plastic in the stomach".* Implementation of this 'Fulmar-Litter-EcoQO' started in 2002 in the EU project 'Save the North Sea'. Data show that 40% to 60% of Fulmars in the North Sea currently exceed the critical value of 0.1 gram of plastic in the stomach. In addition of being a valuable policy instrument, the image of 'birds with plastic in their stomach' attracts much public attention and stimulates awareness and changed behaviour among stakeholders. Fulmars are foolish foragers, but by being 'quantifiable fools', they can contribute to improved ecological quality for the benefit of all.

Jan van Franeker, PhD, is a senior scientist at the Ecology department on Texel of the Netherlands Institute for Marine Resources and Ecosystem Studies (IMARES). Van Franeker is a marine biologist and has his main expertise in seabirds and other marine top predators, with a focus on their functioning in polar marine ecosystems, especially the Southern Ocean. SInce 1986 is project leader for the Antarctic Research conducted by IMARES. Throughout his career, pollution issues in relation to marine wildlife have been a recurrent phenomenon. In recent years he has guided important projects on monitoring the ingestion rates of litter by seabirds. Formerly a government research instutute for the Ministry of Agriculture, Nature and Food Quality, IMARES is now a privatised marine research organisation working under the umbrella of Wageningen University and Research (WUR).

Foolish Fulmars and their contribution to ecological quality

Jan van Franeker
and the
'Save the North Sea' Fulmar study group

Save the North Sea

VenW

NYK LOGISTICS & MEGACARRIER

Martin Heubeck
Mick Mellor
Eric Meek
Keith Fairclough
Dan Turner
Mark Grantham
Stuart Newson
Jane Gollan
Nicole Girard
Gilles le Guillou
Christine Blaize
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Per-Joel Andersson
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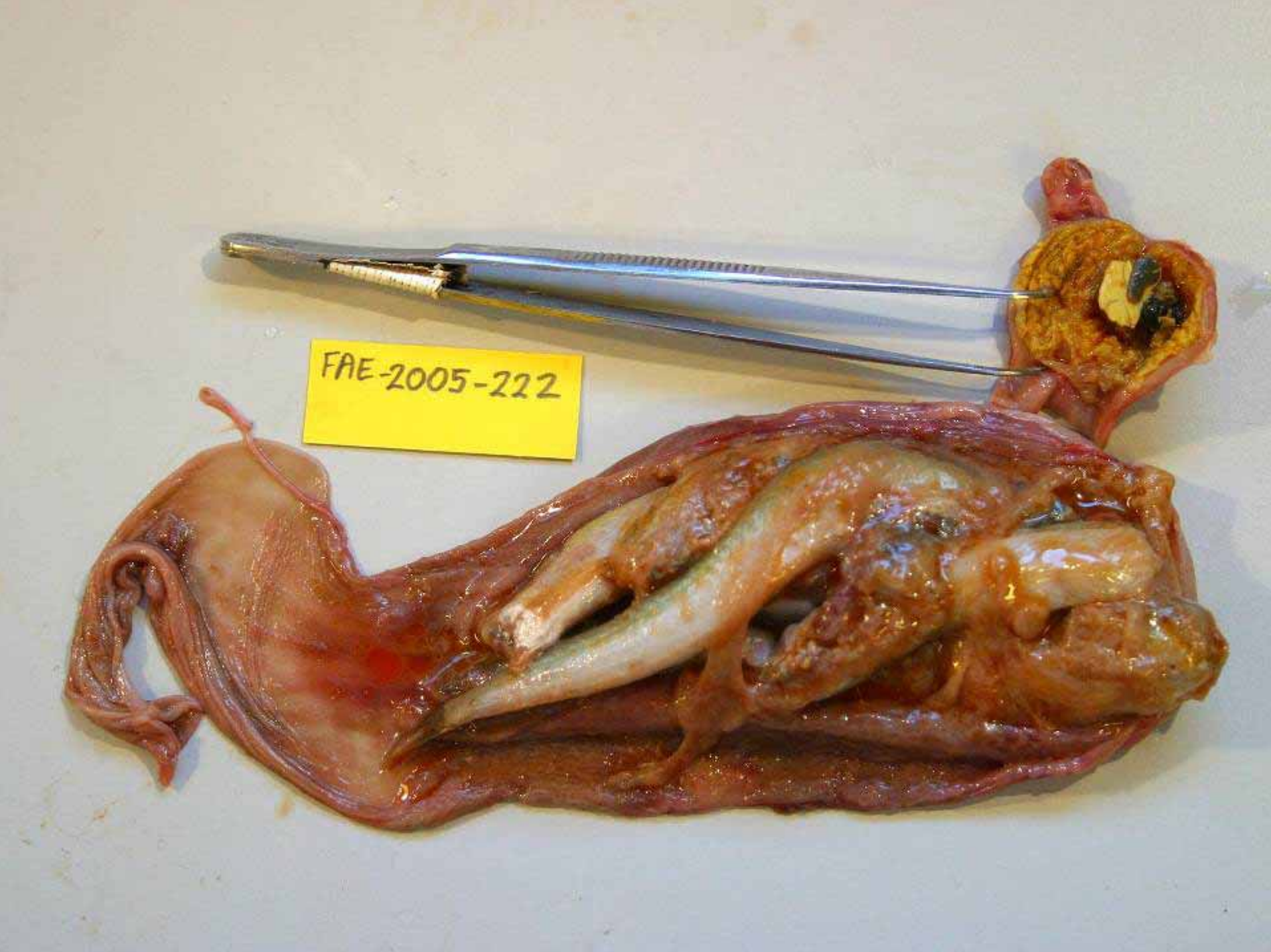
Bergur Olsen
Johannes Danielsen
Jens-Kjeld Jensen
Maria Dam

Wageningen IMARES

WAGENINGEN UR
for quality of life


FAE-2005-222

Fulmars are fools

....

but because of that

they may be

...

a convenient 'tool' for monitoring:

- **numerous, widely distributed, beached birds available**
- **consumes all sorts of litter**
- **feeds exclusively at sea**
- **retains litter in stomach**
- **integrates pollution levels over its oceanic foraging range**

Netherlands

Fulmar-Litter monitoring

1982 - 2004

NZG

VenW

‘North Sea’

Fulmar Study

2002-2006....

Save the North Sea

a project to reduce marine litter

EU Interreg IIIB North Sea Programme

NYK LOGISTICS & MEGACARRIER

Litter types in Fulmar stomachs

industrial plastic

pollutants
chemical ?

non plastic
rubbish

user plastic

- ***sheet***
- ***thread***
- ***foam***
- ***fragment***
- *other*

Stomach content
Fulmarus glacialis
BFP-2234

Stomach content
Fulmarus glacialis
BFP-2155

BFP 2084
proventriculus
gizzard

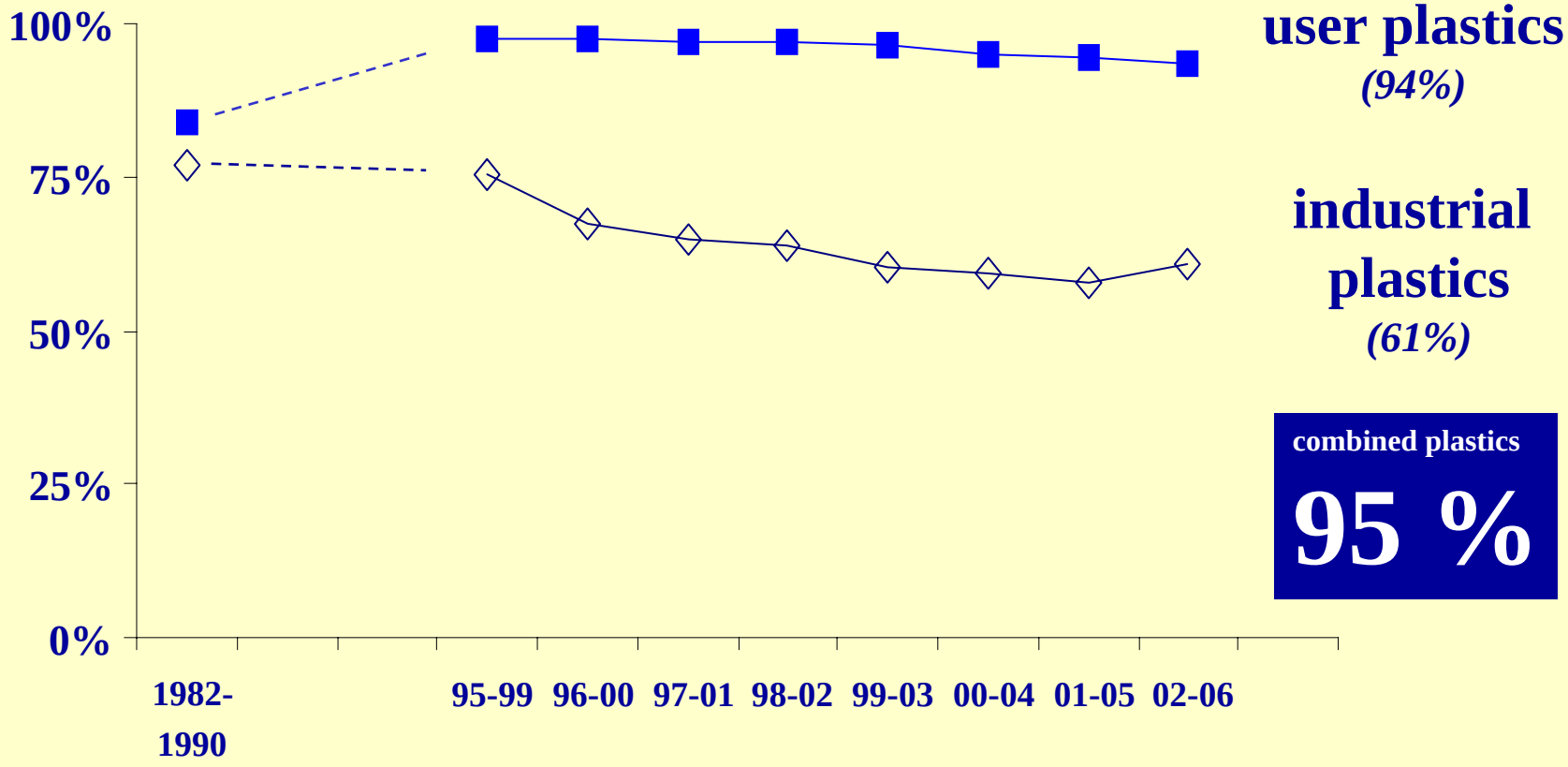
remains of balloon
from stomach of Fulmar
GER-2004-137

Marine litter monitoring Fulmars Netherlands 1982-2006

n = 689

INCIDENCE of plastics

(proportion of birds with plastic in stomach)



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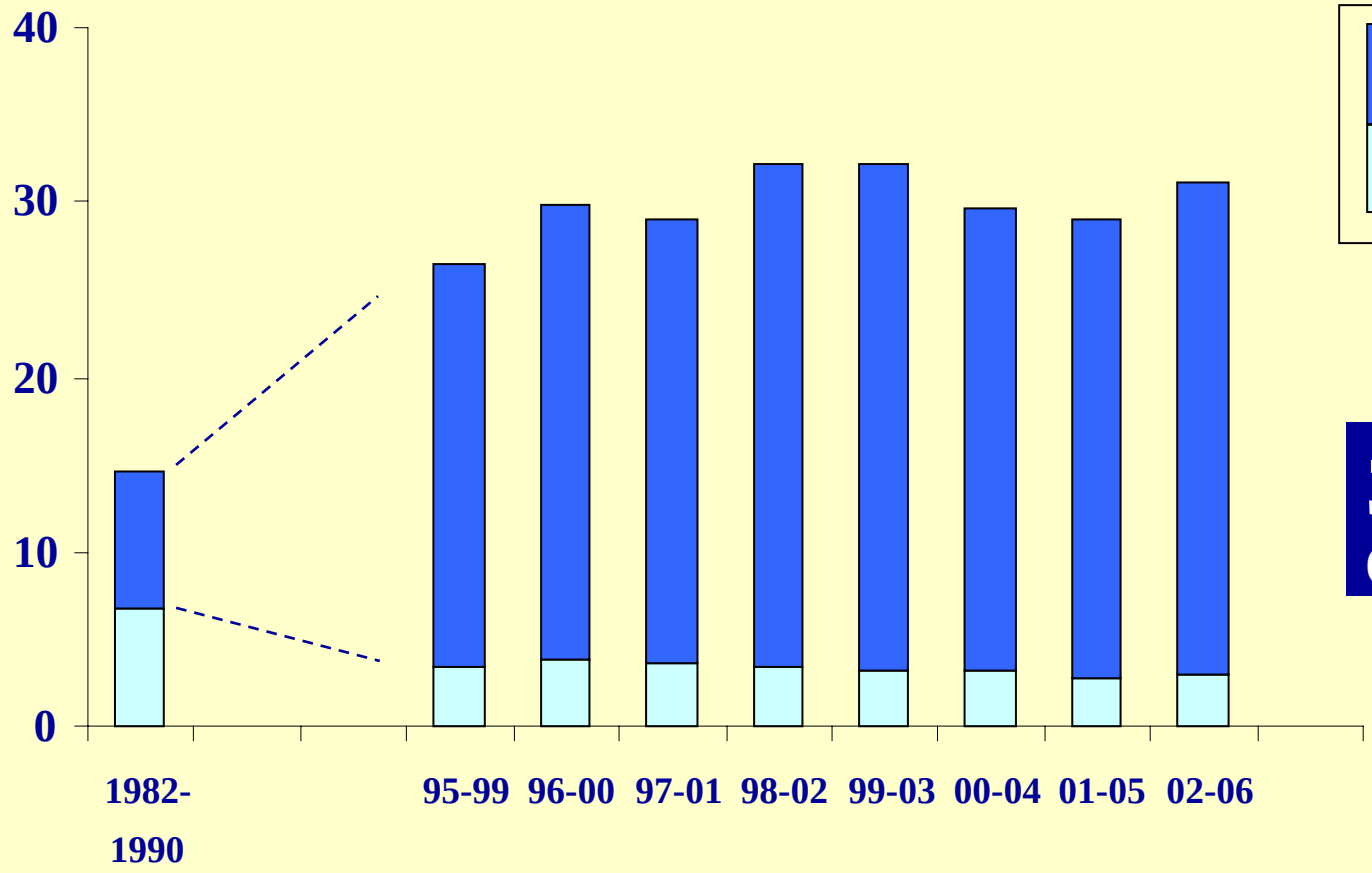
Marine litter monitoring Fulmars Netherlands 1982-2006

n = 689

NUMBER of plastics

(average number of items per bird)



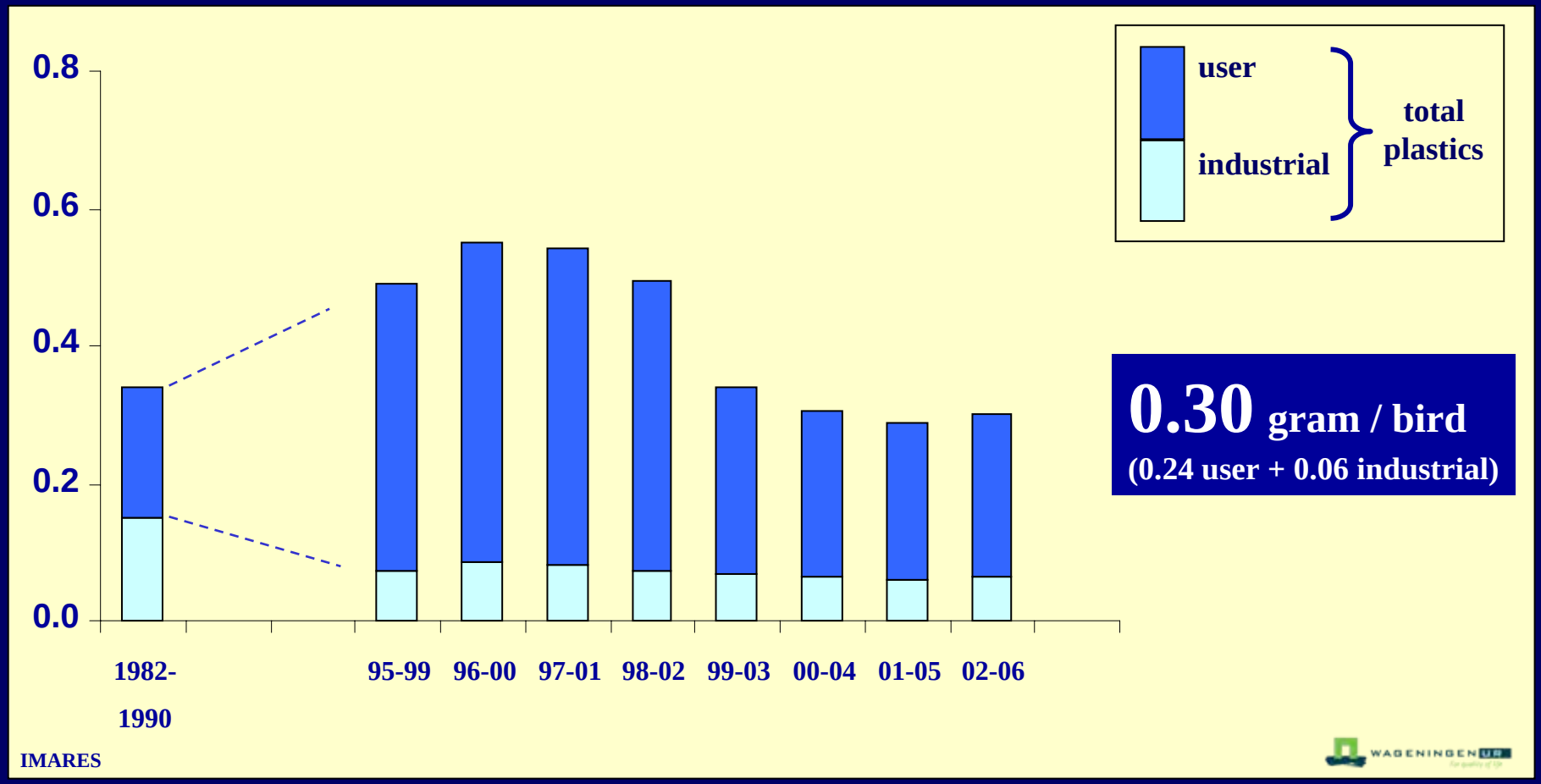
31 pieces / bird
(28 user + 3 industrial)

IMARES

Marine litter monitoring Fulmars Netherlands 1982-2006

MASS of plastics (average in gram per bird)

n = 689

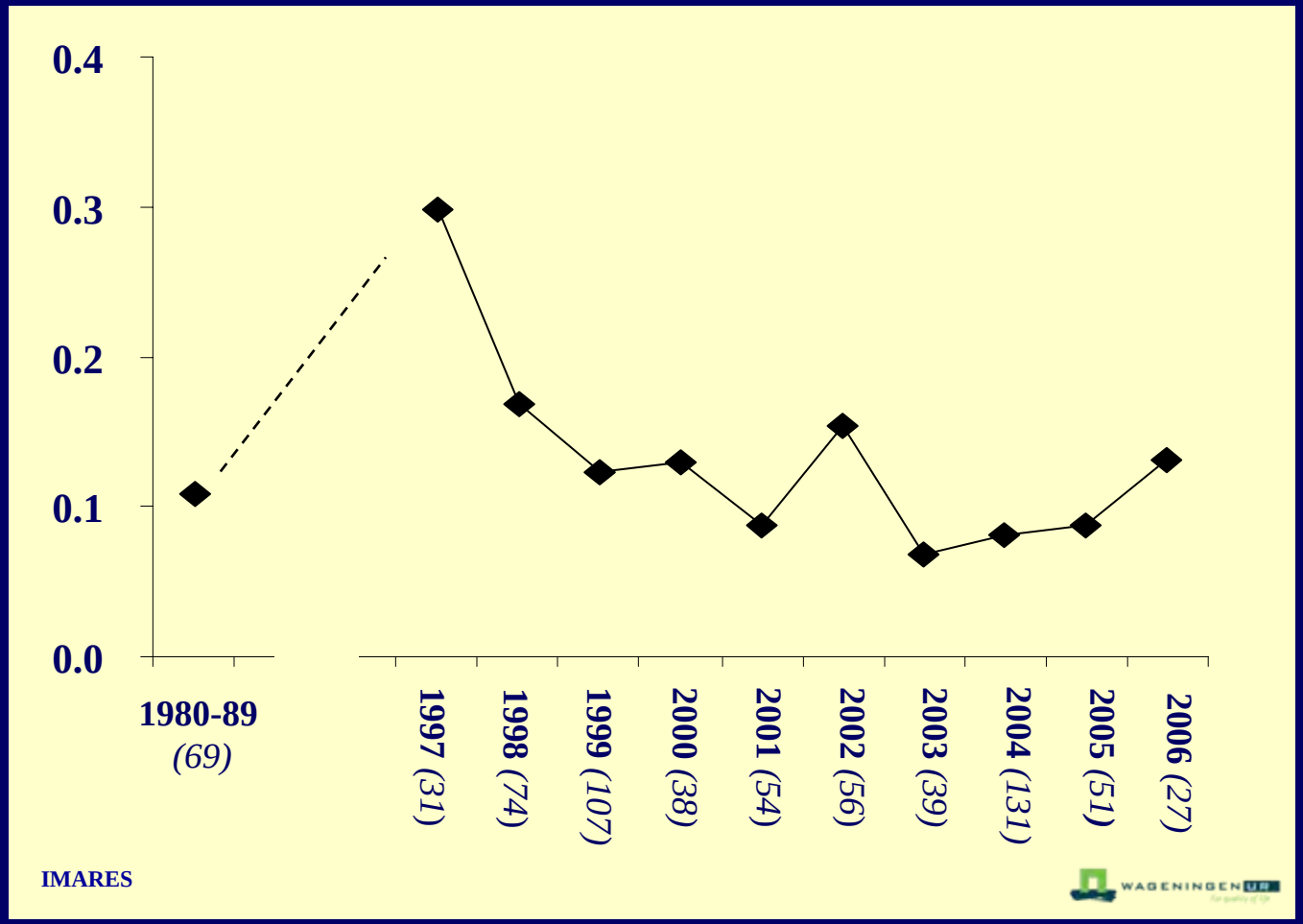


in terms of environmental loads and ecological impacts from ingestion, monitoring by 'mass' is the most relevant

Marine litter monitoring Fulmars Netherlands 1982-2006

Annual data……. Geometric mean mass

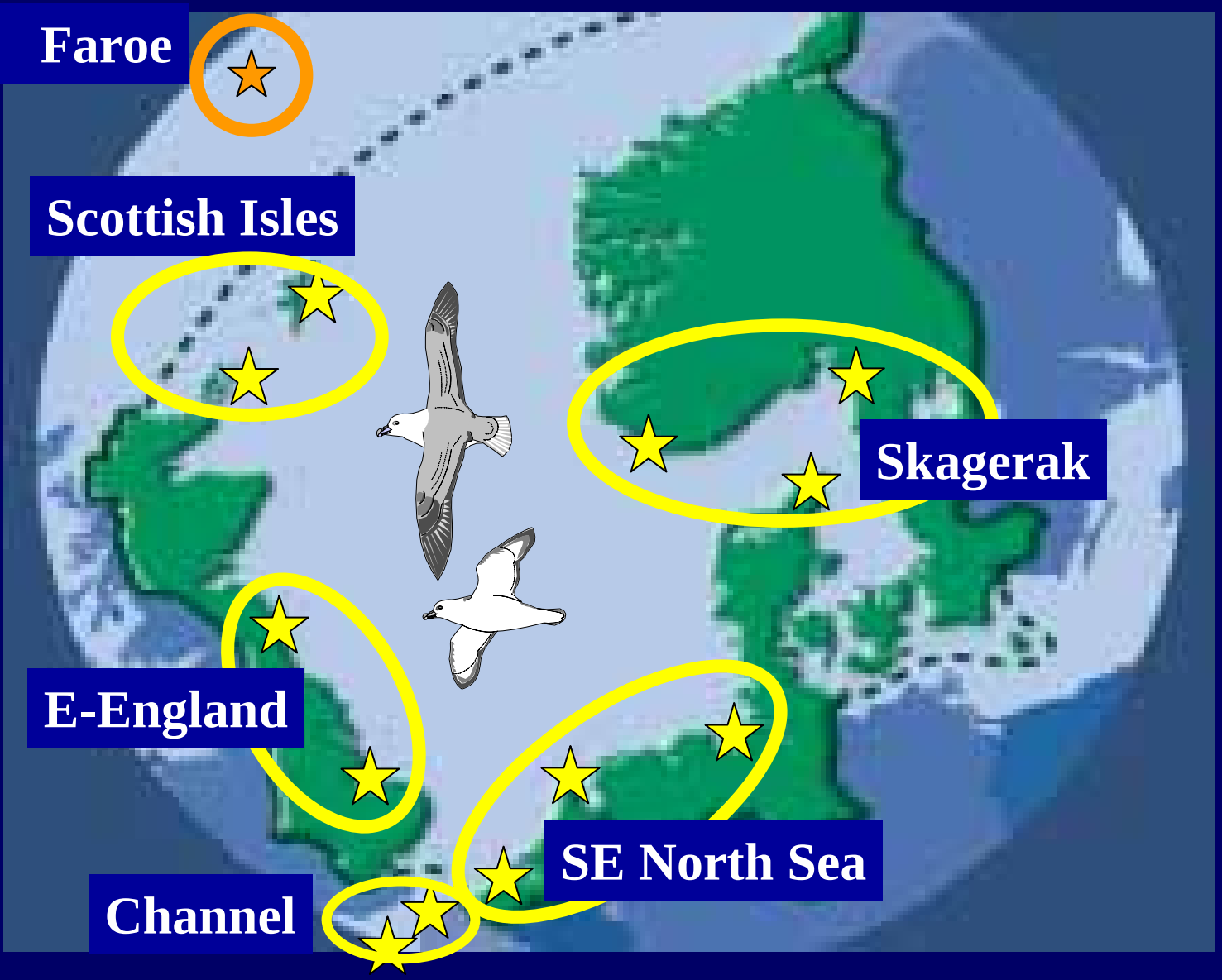
(annual means in gram of plastic per bird)



10-year trend (1997-2006) by linear regression fitting individual data of ln transformed mass of plastic on year of collection

$p < 0.001$ *n=608*

North Sea Fulmar monitoring – 2002-2006



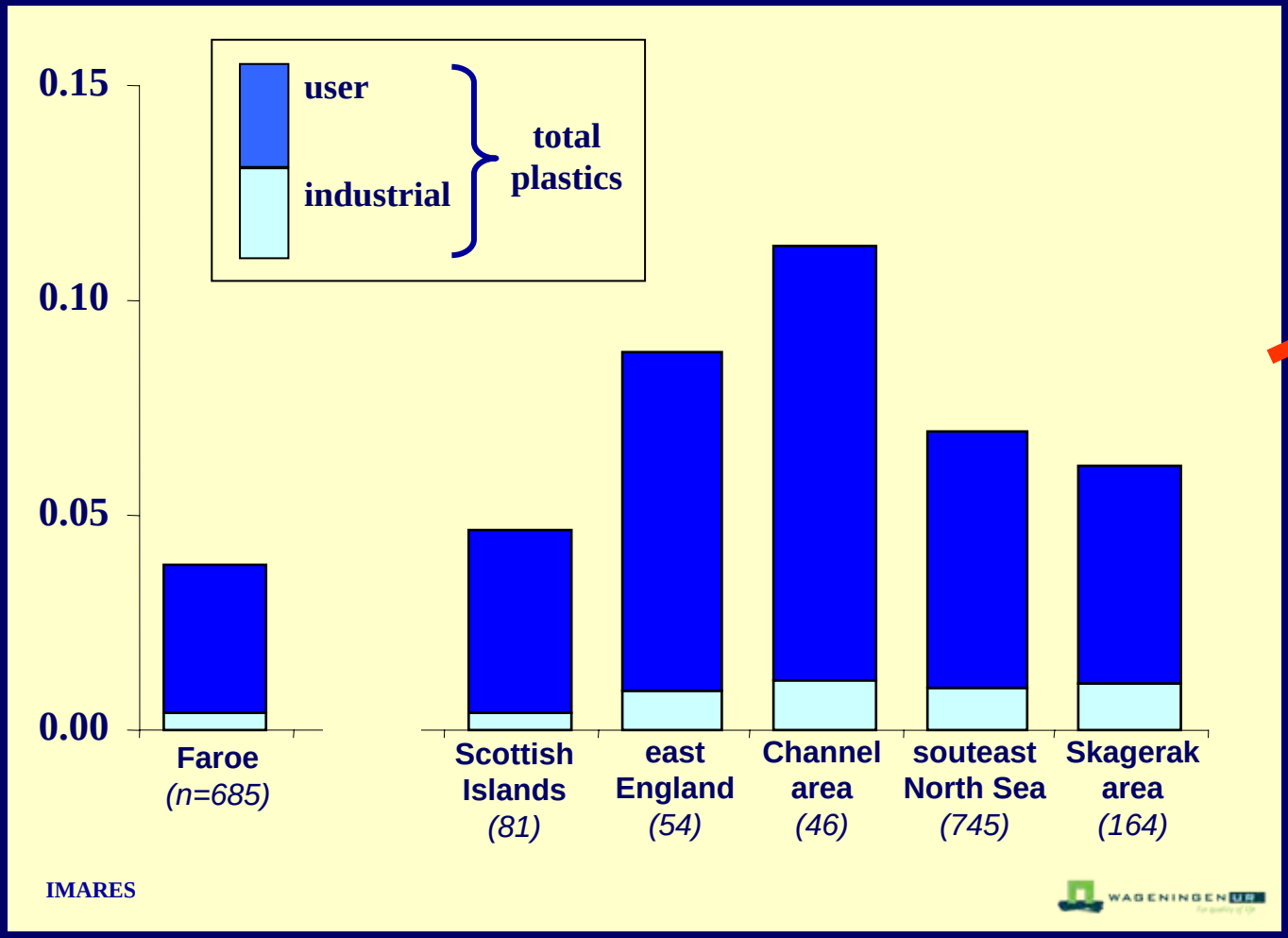
SNS Fulmar study

REGIONAL patterns

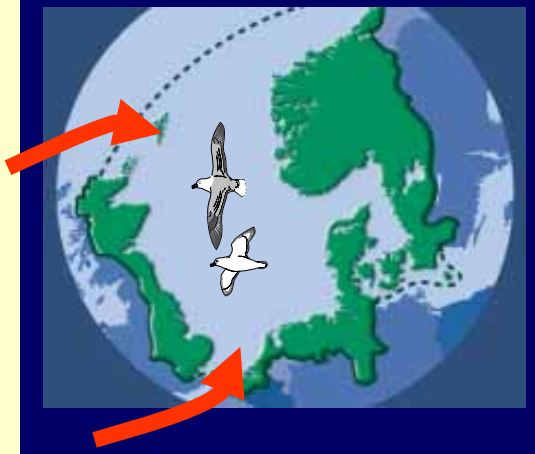
North Sea Fulmar monitoring – 2002-2006

Geometric mean mass

regional means in gram of plastic per bird)



Southern area, in particular Channel, most heavily polluted, i.e. twice level of that in Scottish Islands.



The pattern indicates major local pollution sources *(rather than 'background' from e.g. Gulf Stream)*

marine litter = policy problem

North Sea Ministerial Conference Declaration

(Bergen; March 2002):

Ecological Quality Objectives

for the North Sea

“EcoQO’s”

(= monitoring systems with well defined political target)

OSPAR

EcoQO example:

EcoQO on oil pollution in the North Sea

Quality element

Beached Guillemots

Objective

the proportion of Guillemots with oil must be 10% or less of the total found

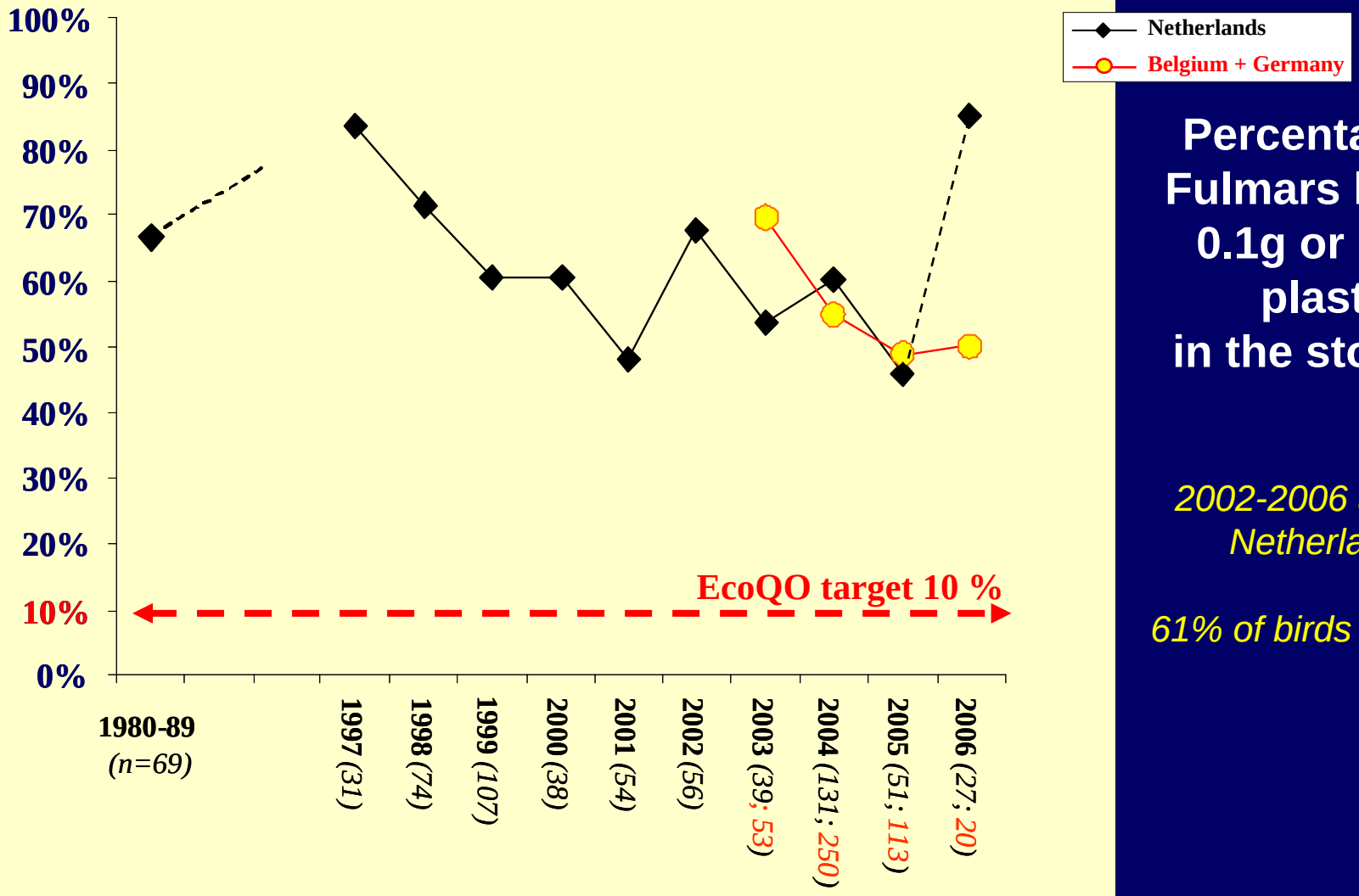
(all regions, for at least 5 years)

EcoQO on litter pollution in the North Sea

Quality element
beached Northern Fulmars

Objective (preliminary)
the proportion of Fulmars with more than 0.1g of plastic in the stomach must be 10% or less of the total found
(all regions, for at least 5 years)

OSPAR EcoQO target for marine litter in the North Sea
Trend and current level in the Netherlands



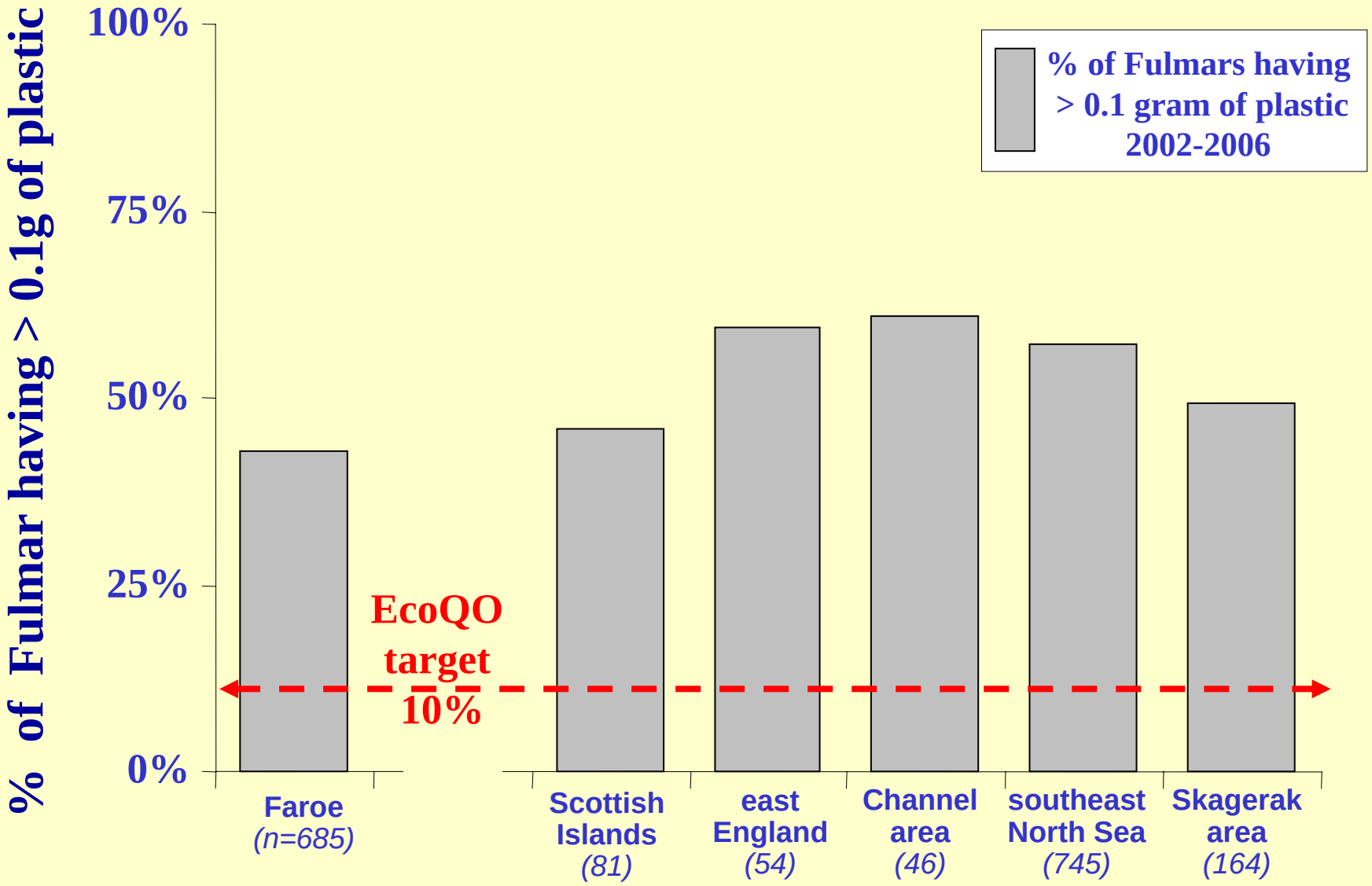
Percentage of Fulmars having 0.1g or more plastic in the stomach

2002-2006 average Netherlands:

61% of birds over 0.1g

IMARES

OSPAR EcoQO target for marine litter in the North Sea
current levels *(5 year averages)* in different regions

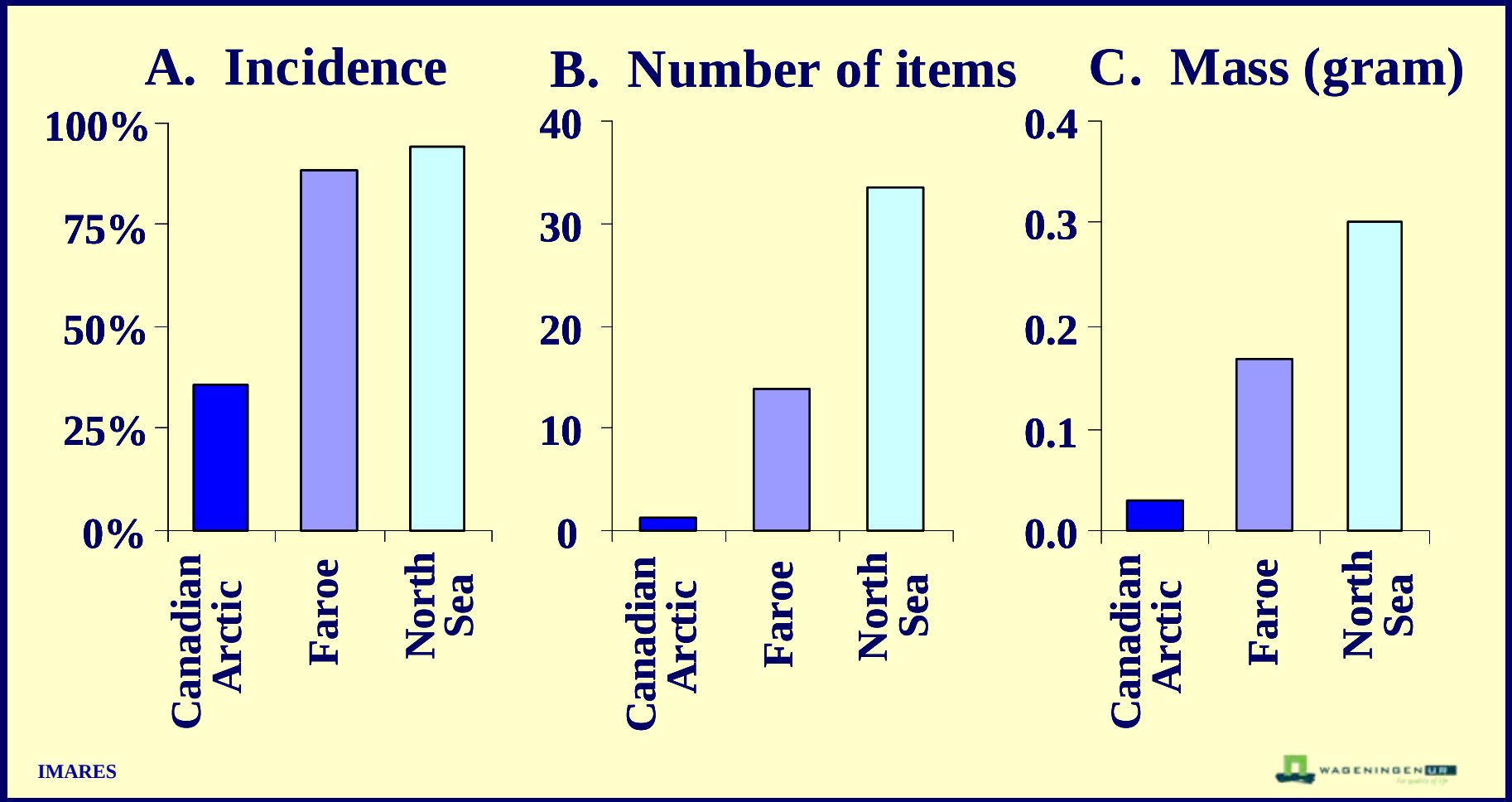


IMARES

Scope for improvement ?

North Atlantic comparison

Data Canadian Arctic from Mallory *et al.* (2006), Mar.Pollut.Bul. 52: 813-815



John Mouat Rick Nickerson Melanie Schultz van Haegen
(NL North Sea Deputy Minister)

Fulmar
=
attractive and convincing fool and tool for policy *and* general public in working towards improved ecological quality in the North Sea

Fulmar - symbol of the
Save the North Sea
marine litter campaign

to the benefit of
all marine life

Salko de Wolf, EcoMare

G.Mauger, - GECC

Fulmars in the North Sea
contribute to ecological quality
also, by “digesting” per year an estimated *

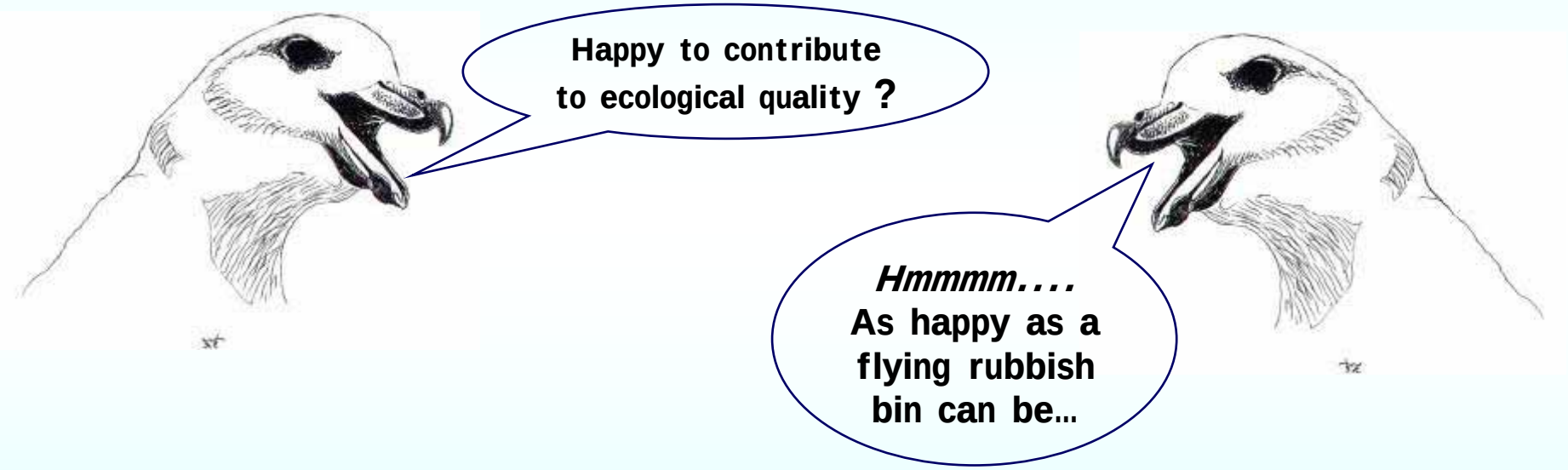
- **750 million plastic particles**
- **representing over 6 ton of plastic**
- ***plus a wide range of other waste products***

*** Approximately 2 million Fulmars live within the North Sea area, seasonally fluctuating between 1 and 3 million (***Skov et al 1995***). During a year, there are about 24 million ‘Fulmar months’ in the North Sea**

The average stomach load of plastics of Fulmars in the North Sea is ± 40 particles weighing ± 0.3 gram *(van Franeker et al. 2005).* **Thus, at any moment over 80 million plastic particles, or 670 kg plastic is “flying around” inside Fulmars. A conservative estimate is that ± 75% of such a stomach load is “digested” and excreted within a month time** *(observations on Antarctic species; van Franeker et al 2001)*

reports and info:
www.zeevogelgroep.nl

click downloads



Thank you for listening

Incidence of Marine Debris Ingestion in Seabirds from Midway Atoll and Heard Island

Dr. Heidi J. Auman, University of Tasmania, Hobart, Tasmania, AUSTRALIA

Abstract: The presence of ingested anthropogenic marine debris in seabirds is of growing concern, especially in areas of the earth remote from point sources. Laysan albatross chicks from Midway Atoll, North Pacific Ocean, were assessed for impacts of marine debris ingestion. Masses and incidence of debris in chicks were compared between birds found dead of natural causes and those injured by vehicles. Laysan albatross chicks dead from natural causes had significantly greater masses of plastic debris in their proventriculi and gizzards and had significantly lighter body masses and lower fat indices than injured but otherwise healthy chicks. In a separate study of seabirds from Heard Island in the Southern Indian Ocean, small amounts of ingested marine debris were found in two Antarctic prions and evidence of indirectly ingested debris were found from the casts of sub-Antarctic skuas. Ingested marine debris probably does not cause significant direct mortality in these seabirds, but is likely to cause physiological stress as a result of satiation and mechanical blockages.

Heidi J. Auman, PhD, earned a B.S. in Biology from Alma College, a M.Sc. in Fisheries and Wildlife from Michigan State University, and a Ph.D. in Zoology from the University of Tasmania. She has spent the last 20 years focusing on human impacts in seabirds, specifically in the topics of toxicology, disturbance, plastic debris ingestion, urbanisation and diet. Her research is global in scope with a preference for isolated islands, including those in the North American Great Lakes, subtropical Midway Atoll, subantarctic Heard Island and Tasmania. A popular science communicator, she has demonstrated that our ecological footprint has reached the furthest corners of the Earth, often with disturbing consequences.

Incidence of Marine Debris Ingestion in Seabirds from Midway Atoll and Heard Island

Heidi J. Auman

Midway Atoll
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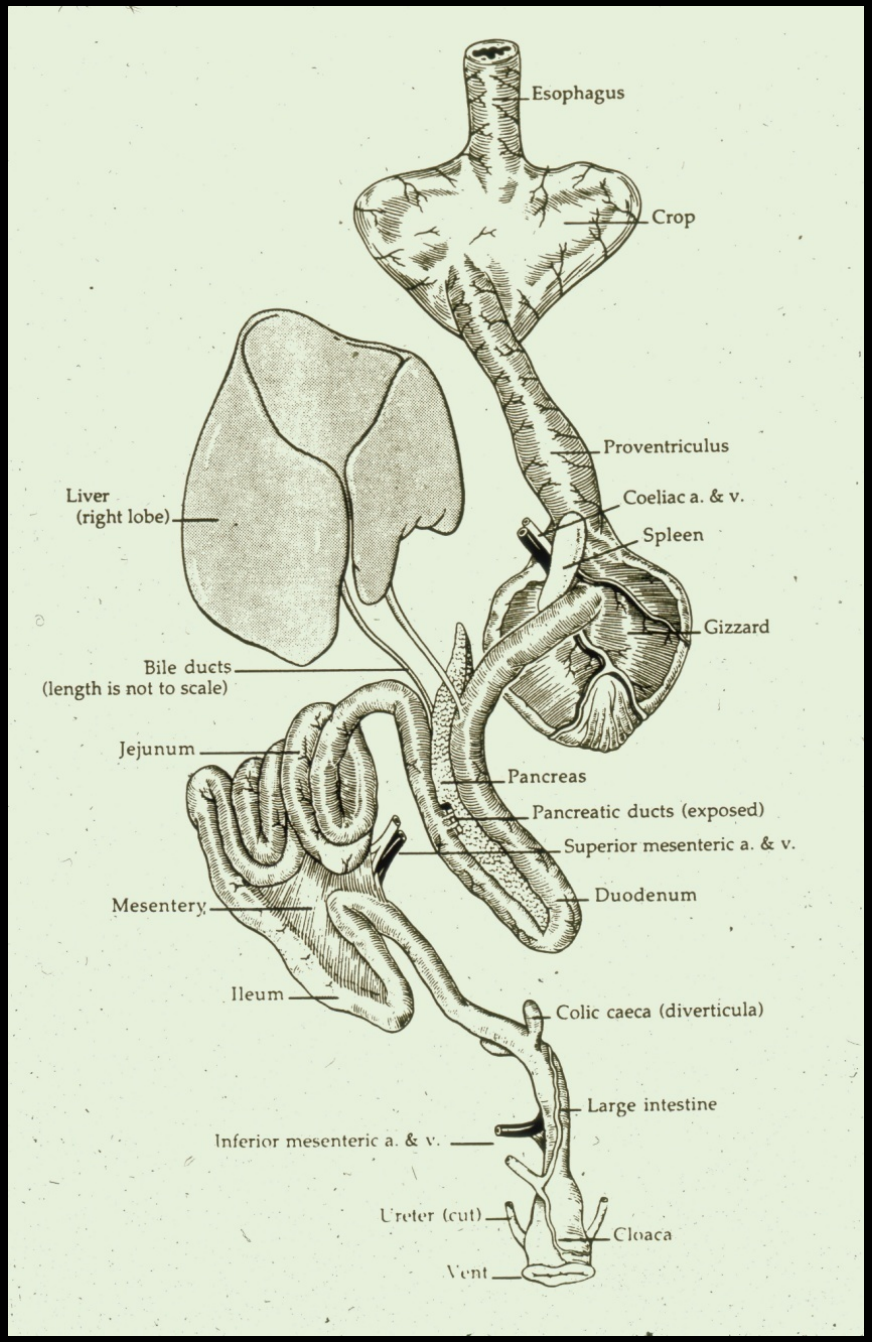
BIRDS ONLY
Beyond
This
Sign

Hypothesis

- Laysan albatross chicks found dead and accidentally injured chicks do not differ in masses of ingested plastic debris.



Manual of Ornithology,
Proctor and Lynch, 1993

www.wfu.edu/biology/albatross/hawaii/plastic.jpg

Auman et al. 1998

Auman et al. 1998

Items found in albatross chicks

- Chips/shards of unidentified plastic debris, rubber pieces, bottle caps, beads, Styrofoam, O-rings, fishing line, rope, buttons, checkers, disposable lighters, toys, PVC pipe, golf tees, magic markers, light bulbs, medical waste, dishwashing gloves, light sticks, toothbrushes

- Squid beaks, *Casuarina* pine cones, peach pits, walnuts, twigs, wood chips, pumice

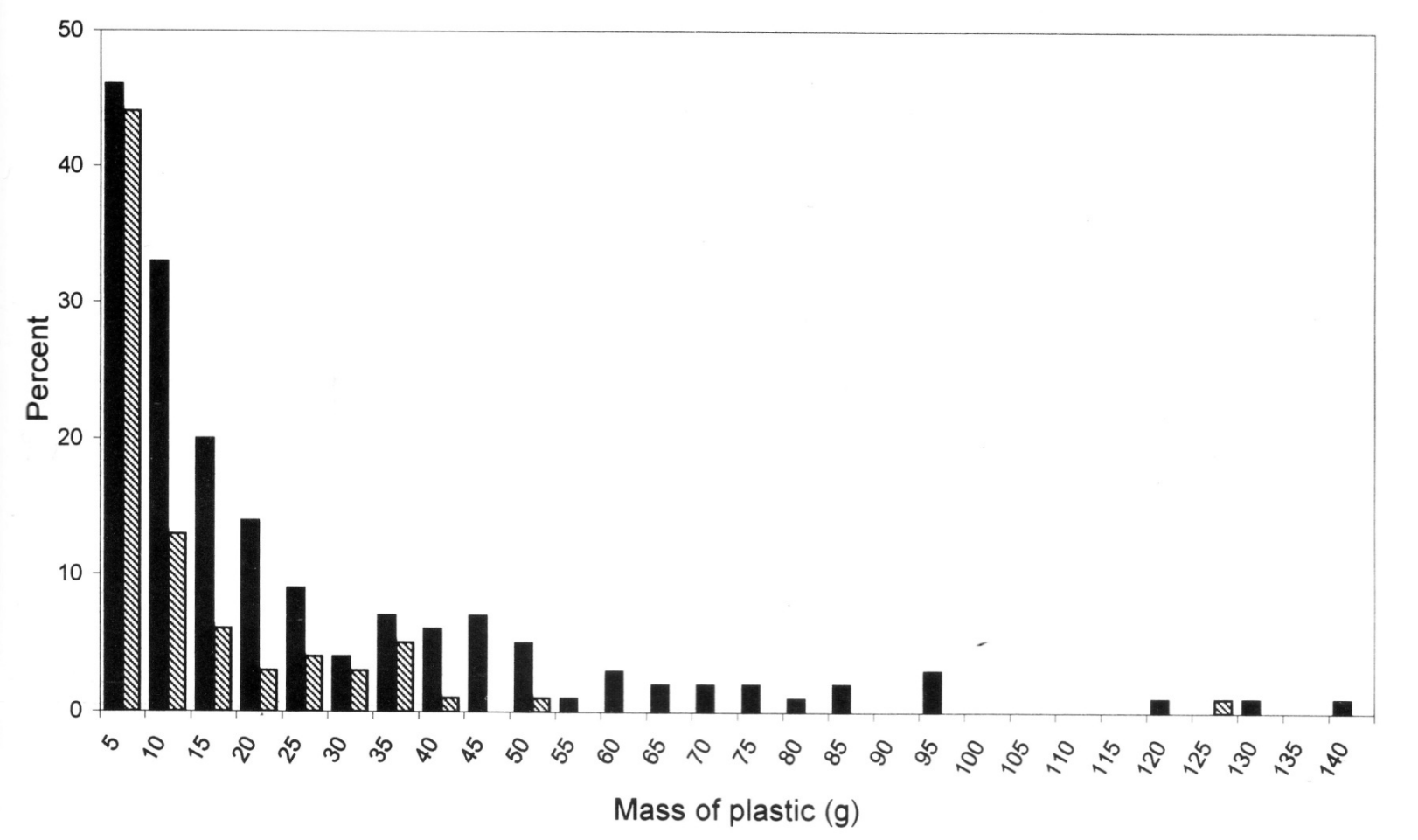
Results – Midway necropsies

- 1994: 95 dead and 39 injured chicks
  - Dead 23.8 g plastic debris
  - Injured 11.3 g ($p = 0.0001$)
- 1995: 76 dead and 41 injured chicks
  - Dead 18.1 g plastic debris
  - Injured 9.5 g ($p = 0.01$)
- Largest plastic pieces in dead chicks significantly larger than those in injured chicks ($p = 0.0099$)

Results – Midway necropsies

- Only 6 of 251 chicks (2.4%) contained **no** marine debris
- Of 62 LAAL adults necropsied 1992-1994, 4 had scars on the proventriculus; one with 11.3 cm piece protruding from body

Mass of plastic debris in 171 dead and 80 injured albatross chicks



Auman et al. 1998

Color preferences from 1307 lighters

Color	Blue	Orange	Green	Yellow	Red + Pink	Purple	White	Black
#	120	249	228	88	274	104	220	24
%	9.2	19.1	17.4	7.3	21.0	8.0	16.8	1.8

Cooper et al. 2004

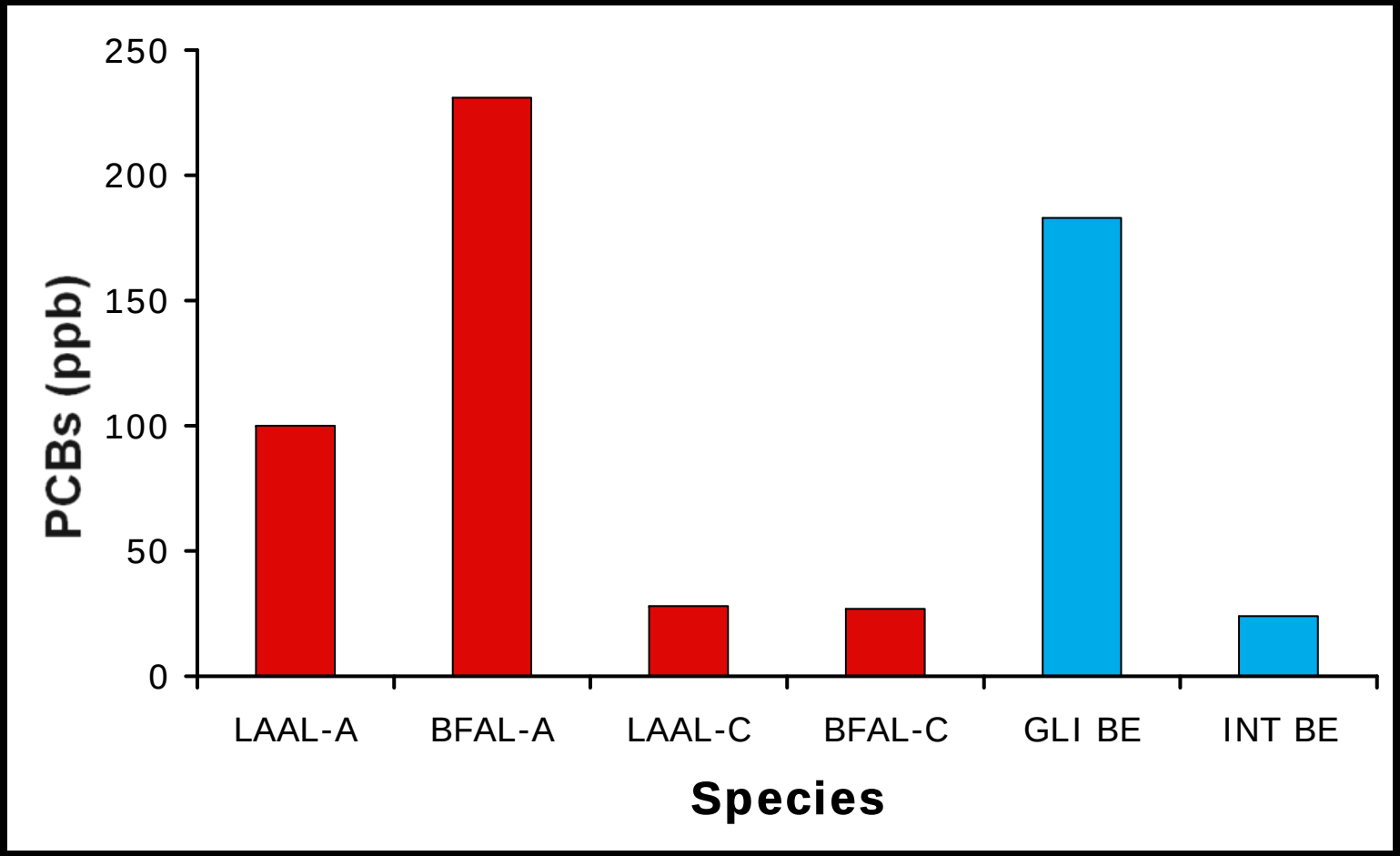
Physiological impacts of plastic debris on albatross chicks

- Starvation/Satiation
- Dehydration
- Lower fledging weights
- Decreased fat deposition
- Punctures and ulcerations
- Obstructions

Toxicological impacts

- Colorants, softeners and antioxidants used in conversion to user-friendly plastics may be harmful toxicants
- Burned/melted plastics likely a source of dioxins and furans - detected in LAAL eggs, fat and blood
- PCBs adsorb to oceanic plastic debris up to 5 ppm
- Large masses of plastics a source of PCBs in addition to dietary sources?

Total PCBs in blood of birds from Midway vs. the U.S. Great Lakes



Auman et al. 1997

North Pacific Currents

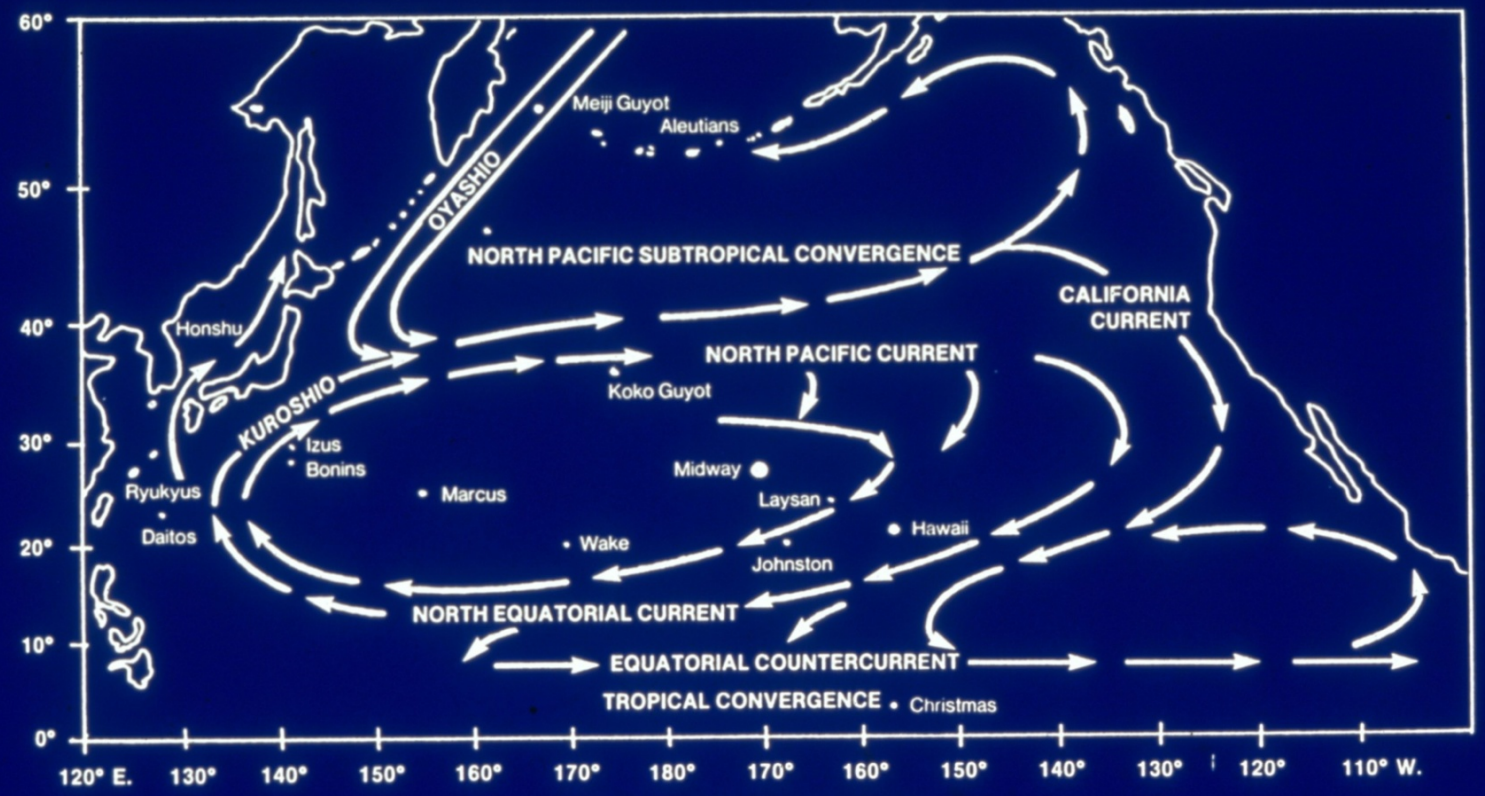
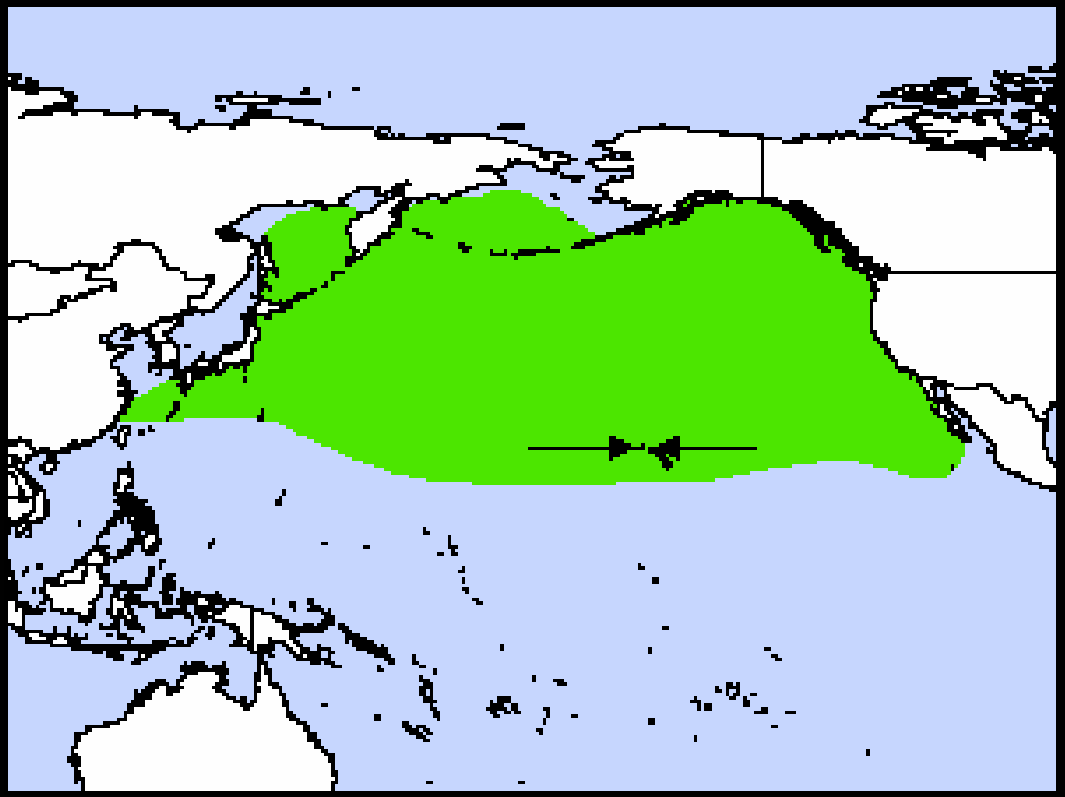


Figure 2. The North Pacific

Harrison, Seabirds of Hawaii, 1990

Laysan albatross range



BirdLife International

Conclusions - Midway

- Dead Laysan albatross chicks had significantly greater masses of ingested plastic debris than injured chicks
- Dead chicks had significantly lighter body weights than injured chicks
- Dead chicks had significantly less fat reserves than injured chicks
- Controlled studies not ethically possible with albatross chicks, not truly comparable to chickens force-fed plastic pellets

Conclusions - Midway

- Ingested debris is probably not a significant direct cause of death, but likely to cause physiological distress
- May be a ‘third strike’ against chicks already suffering from starvation, inexperienced parents, poor weather, stress, disease, parasites, injury or other stressors
- Replicate study to determine if incidence and impacts have changed since 1994-1995?

Heard
Island
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HP33
7

Results – Heard Island necropsies (October 2000 - January 2001, Atlas Cove)

10 South Georgian diving petrels

4 sub-Antarctic skuas

1 southern giant petrel

1 unidentified diving petrel

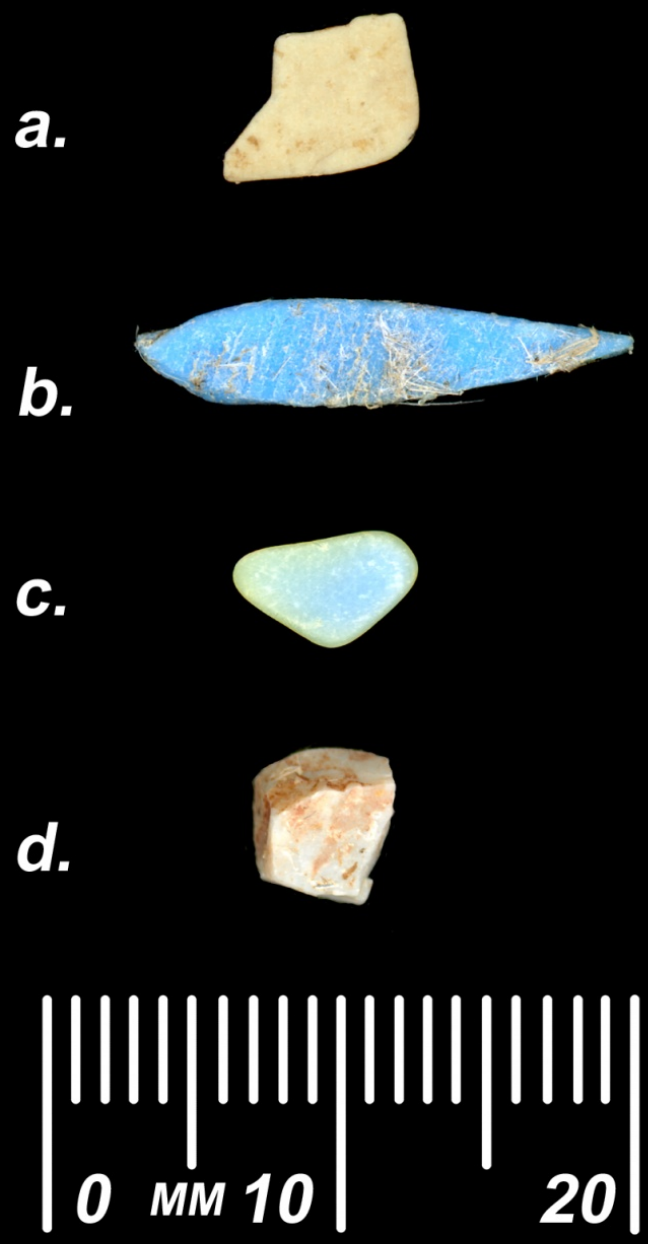
2 Antarctic prions

- Contained plastic debris
- Surface seize prey

Indirect Ingestion of Marine Debris

Results – cast examination

- 396 sub-Antarctic skua casts dissected
- 2 (0.5%) contained plastic debris



Auman et al. 2003

Conclusions – Heard Island

- Debris particles in prions currently not likely to pose physiological threats
- Skuas normally egest indigestible remains – debris not likely to pose problems
- Presence of marine debris in remote locations remains troubling
- Larger sample sizes, more species (i.e. albatross) would be helpful
- Long-term monitoring recommended

References

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- Auman, H.J., J.P. Ludwig, J.P. Giesy and T. Colborn. 1998. Plastic Ingestion by Laysan Albatross chicks on Sand Island, Midway Atoll in 1994 and 1995. *In*: Albatross Biology and Conservation. (G. Robertson and R. Gales, eds.). Surrey, Beatty and Sons. Chapter 20.
- Auman, H.J., J.P. Ludwig, C.L. Summer, D.A. Verbrugge, K.L. Froese, T. Colborn and J.P. Giesy. 1997. PCBs, DDE and TCDD-EQ in two species of albatross on Sand Island, Midway Atoll, North Pacific Ocean. *Environmental Toxicology and Chemistry* 16:498-504.

Acknowledgements

- USFWS, Midway Atoll National Wildlife Refuge
- Midway Atoll Naval Air Facility
- US Environmental Protection Agency
- World Wildlife Fund
- Australian Antarctic Division, Australian National Antarctic Research Expeditions
- University of Washington Tacoma and National Oceanic and Atmospheric Administration Marine Debris Program

Ingestion of microplastics by marine invertebrates

Dr. RC Thompson, University of Plymouth, Plymouth, UK

Abstract: Microplastics are small fragments of plastic debris. This type of material has been reported on a global scale and is present in the water column, on shorelines and in subtidal sediments. Large items of plastic debris are known to have potentially harmful effects on over 260 marine species, principally via ingestion and entanglement. Because of their size microplastics have the potential to be ingested by a much wider range of organisms including relatively small invertebrates.

In laboratory experiments the filter feeder, *Semibalanus balanoides*; the infaunal deposit feeder, *Arenicola marina* and the detritivore, *Orchestia gammarellus* all ingested microplastic fragments (20 - 2000µm diameter) over a period of several days. Subsequent experiments with the common mussel (*Mytilus edulis*) showed that plastic microspheres (3.0 and 9.6 µm) were ingested and within 3 days had translocated from the gut to the haemolymph (circulatory system). These particles were still present in the haemolymph 48 days after transfer to clean conditions, but no adverse biological effects were detected. It is apparent therefore that invertebrates with a range feeding strategies can ingest microplastics and that this debris may be retained in theirbodies.

Ingestion of microplastic could impair feeding in a similar way to that already described for larger items of debris. There is also concern that ingestion of small items of plastic debris could facilitate the transport of toxic chemicals to marine organisms. Our recent experiments support this possibility, but more work will be required to reach firm conclusions. As a precursor we need to establish whether there are particular 'sinks' for the accumulation of microplastic debris and to establish the extent to which organisms are ingesting microplastics in these habitats. Some creatures, such as sea birds, are known to actively select plastic fragments mistaking them for food items at the sea surface. As a consequence of habitat and/or behaviour some organisms may therefore be exposed to greater quantities of microplastics than others. Hence, data on natural levels of exposure are crucial to inform the choice of appropriate test organisms.

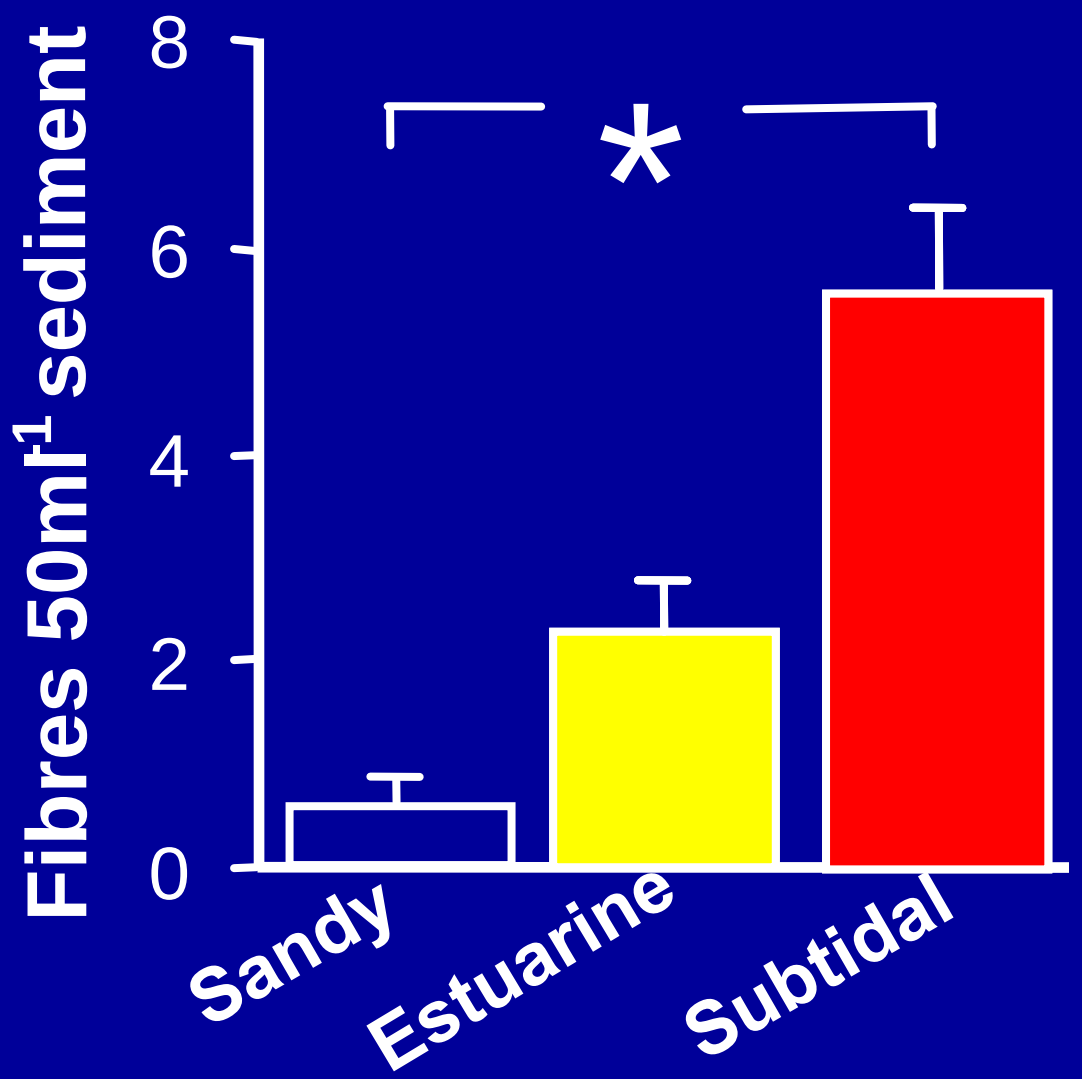
Richard C. Thompson, PhD, is a Marine Ecologist specialising in the ecology of shallow water marine habitats. He studied Marine Biology at the University of Newcastle upon Tyne from 1988 to 1991 followed by a PhD on the ecology of intertidal biofilms at the University of Liverpool from 1992 to 1996. He subsequently worked as postdoctoral research fellow at the University of Southampton and since 2001 he has been a lecturer, and is now a Reader, in Marine Ecology at the University of Plymouth. He currently leads the BSc Marine Biology degree programme at Plymouth and lecture in marine ecology and experimental biology. His research has focused on a wide range of 'natural' ecological interactions and on anthropogenic disturbance. He supervises a research group of 2 post docs and 8 PhD students. Work by his group has examined: biodiversity and ecosystem function using rockpools as natural mesocosms, trade-offs between food availability and refuge quality, trophic linkages between intertidal and subtidal habitats, the ecology of coastal defenses and marine renewable energy developments. Much of his work over the last decade has focused on marine debris. In 2004 his group published a paper in *Science* describing the distribution and temporal trends in the abundance of microscopic fragments of plastic in the NE Atlantic. They have subsequently been working to establish the environmental consequences of this type of debris. He is currently acting as invited editor of a Theme Issue of 13 papers, for Philosophical Transactions of the Royal Society, focusing entirely on Plastics the Environment and Human Health.

Ingestion of Microplastic by Marine Invertebrates

Richard Thompson, University of Plymouth, UK

This presentation as given during the workshop contained unpublished data which has been deleted form the slides that follow here

Microplastic
found in sediments at 20 shores around UK



Thompson *et al.* 2004, *Science*

Environmental consequences of large items

Over 260 species affected worldwide

Most species of turtles

46% of seabird species

43% of marine mammal species

Numerous fish and invertebrate species

For reviews see:

Derriak *et al.* 2002, *Marine Pollution Bulletin;* Laist 1987, Marine Pollution Bulletin

UNEP, 2005; Greenpeace, 2006

IMARES TEXEL

WAGENINGEN UR

photo's by: Dirk Bruin, SBB Vlieland

IMARES TEXEL

WAGENINGEN UR

Fotos: **Salko de Wolf, EcoMare**

Minke Whale

Balaenoptera acutorostrata

stomach contents of young Minke Whale beachwashed in France

IMARES TEXEL

WAGENINGEN UR

Effects of ingestion

Direct cause of death

‘Sublethal’ effects
damage stomach walls
decrease digestion
reduce sensation to feed
reduce stomach volume
absorption toxic substances?

Photo: Algalita Foundation

reduced fitness → *increased indirect mortality*
reduced reproductive success

Impacts of plastic debris invertebrates

Transport invasive species
molluscs, crustaceans, bryozoans
travel long distances on floating debris

Barnes *et al.* 2005, *Marine Biology*

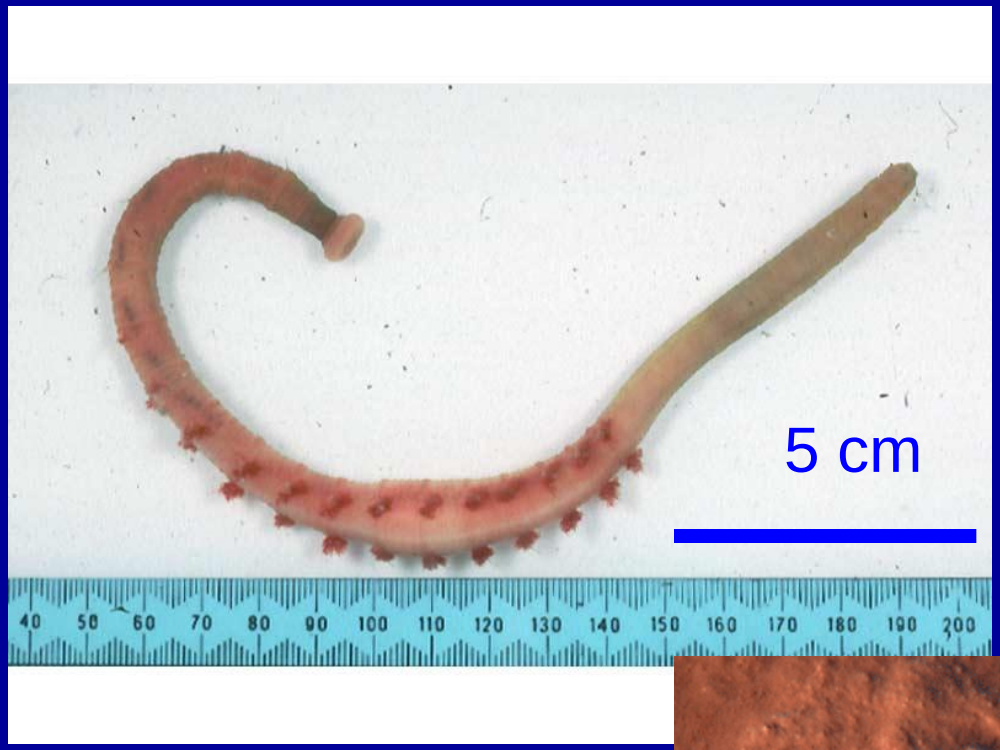
Microplastic also ingested

Barnacle *Semibalanus balanoides*

Filter feeder

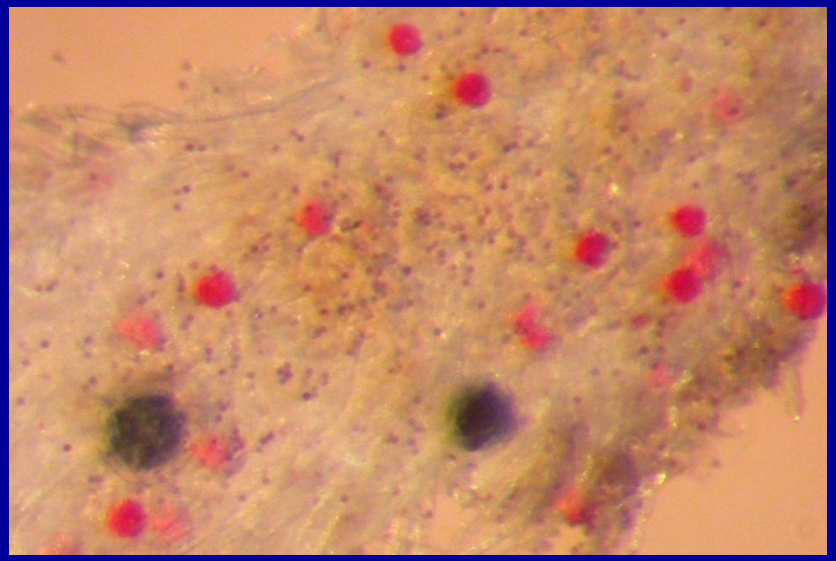
Microplastic also ingested

Lug worm – *Arenicola marina* – deposit feeder



Microplastic also ingested

Sand hopper – *Orchestia gamarellus* detritivore



10 - 100µm fragments

can remain in gut for 20 days

Consequences of ingesting microplastics ongoing work in Plymouth

physical hazard?

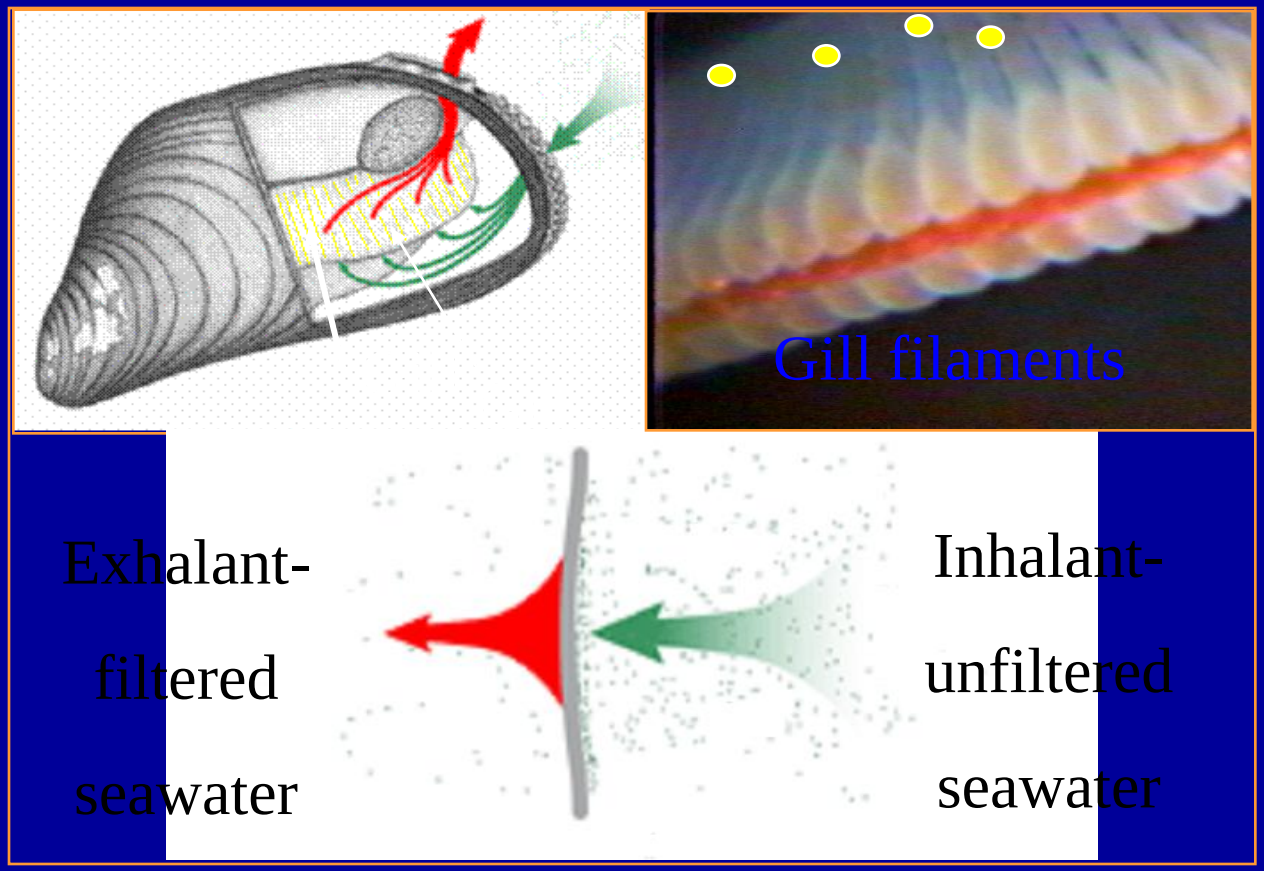
Chemical hazard?

Plastics adsorb hydrophobic pollutants - could desorb when ingested?
(Mato *et al.* 2001, Teuten et al. 2007 *Env. Sci and Technology*)

Chemicals used in manufacture could be released from plastics ?

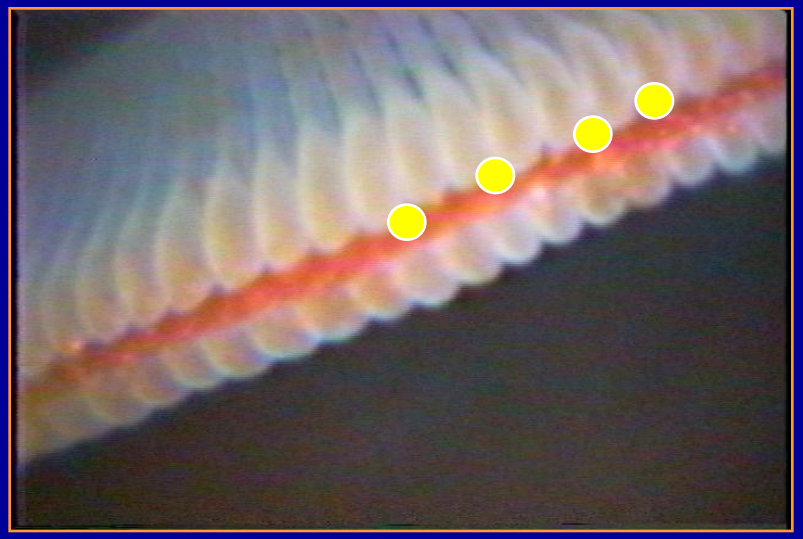
If chemicals transported by plastic do they have toxic effects ?

Particle selection by *M. edulis* previously described using plastic particles



Particles drawn through inhalant siphon and filtered by the gill

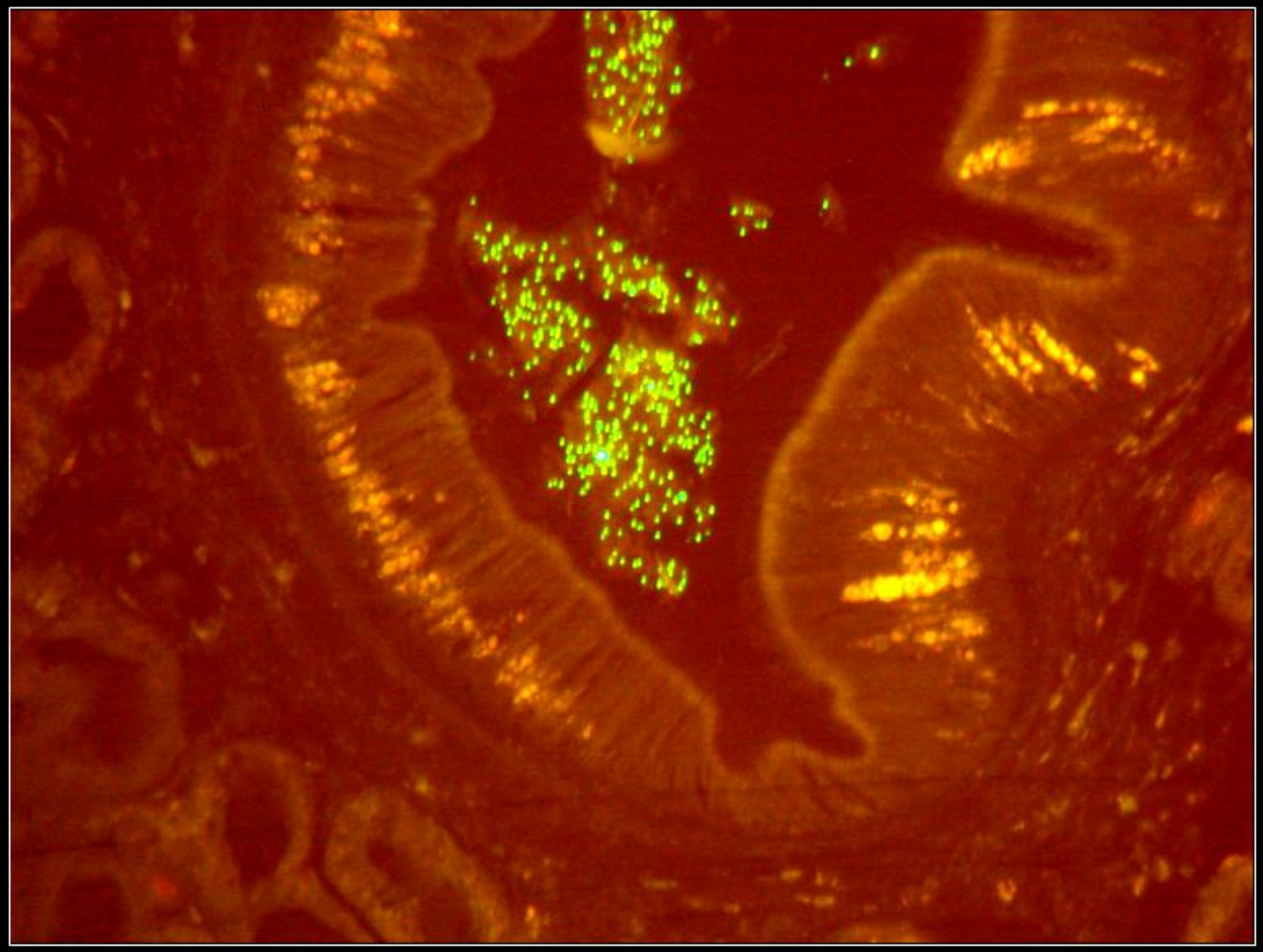
Mucus in ventral groove transports particles to labial palps



Cilia on palps sort particles for ingestion or rejection (pseudofaeces)

Are plastic particles ingested or rejected?

Microplastic is ingested



2 µm microplastic in gut cavity of *M. edulis*

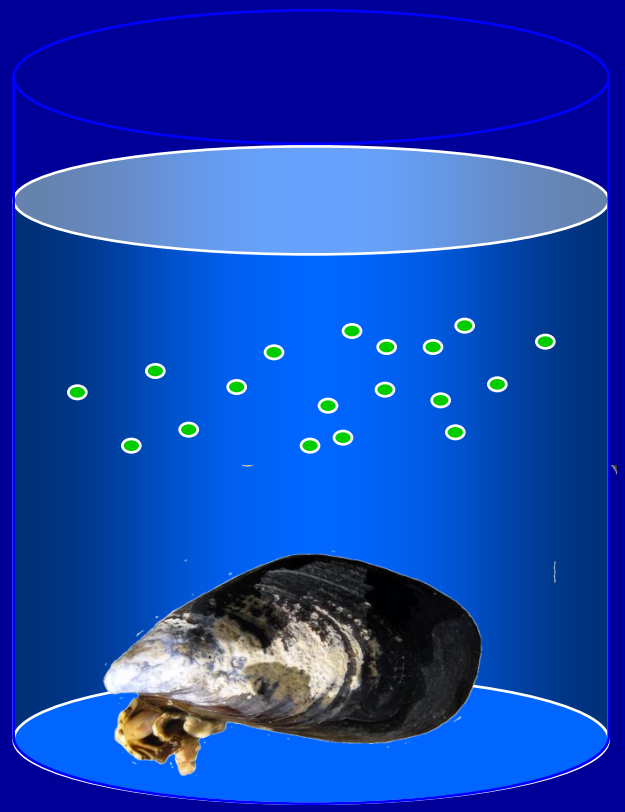
Further experiments using *M. edulis* addressed the following questions

1. Does microplastic accumulate in the circulatory fluid (haemolymph)?
2. When transferred to clean conditions, does abundance of microplastic decline over time?
3. Does size matter? (3.0 *vs*. 9.6 μm)
4. Does microplastic have biological effects?

(Browne et al. 2008)

Microplastic exposure

Phase 1



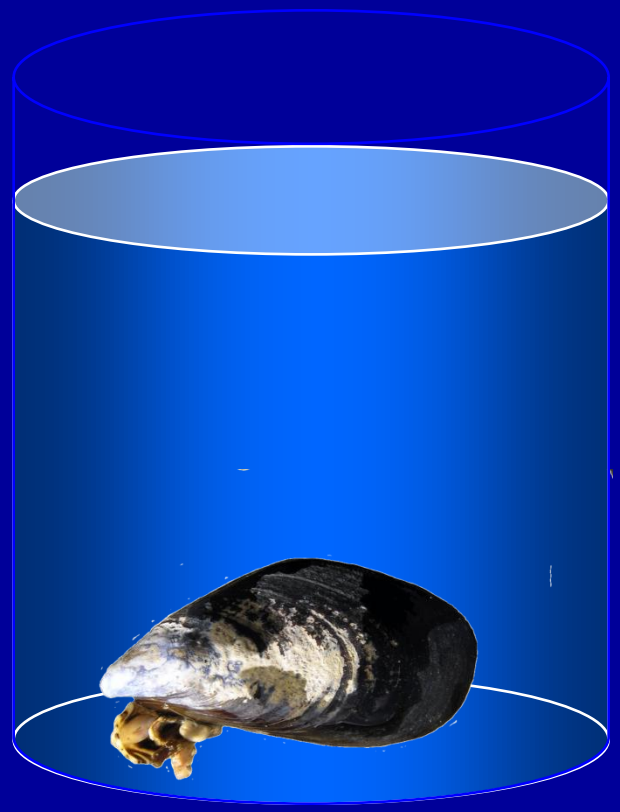
3 hr pulse exposure

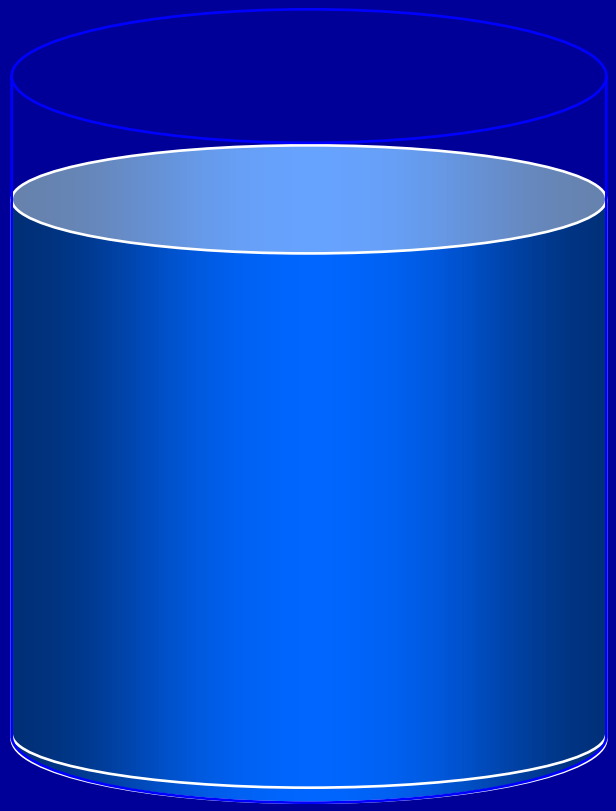
3 treatments

- No microplastic
- 3.0 µm plastic (15K)
- 9.6 µm plastic (15K)

Single pulse exposure

Phase 2: transfer to clean conditions

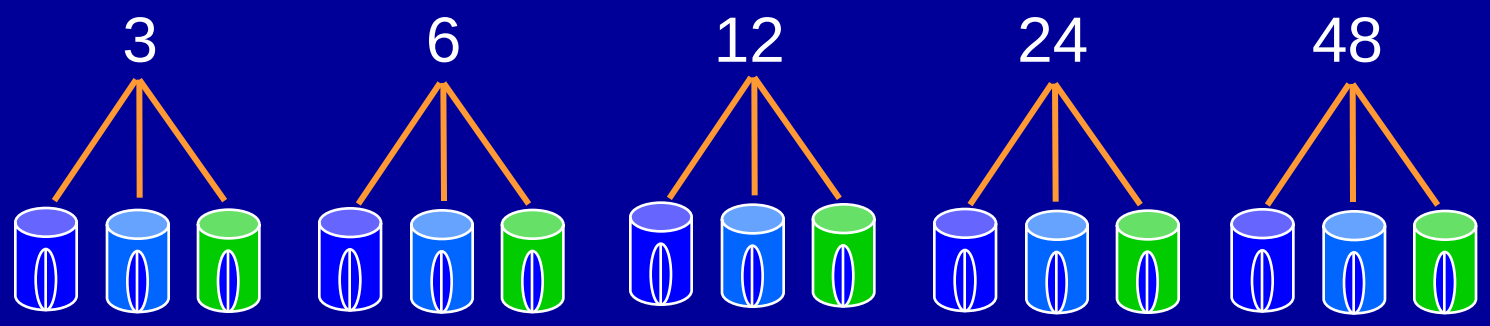




Experimental design

Time (Days)

Treatment (Plastic)



5 Replicates of each time/treatment combination

Plastic Key

No plastic

3.0 µm plastic

9.6 µm plastic

Methods

- Microplastic particles viewed in haemolymph using fluorescence microscopy

Cell function (Cartwright *et al*., 2006)

- Cellular viability
- Phagocytosis

Oxidative status of haemolymph (Hagger *et al*., 2006)

- Ferric Reducing Antioxidant Potential (FRAP)

Feeding behaviour (Widdows & Staff, 1997)

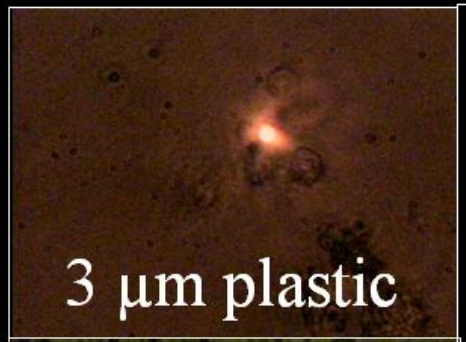
- Clearance rate

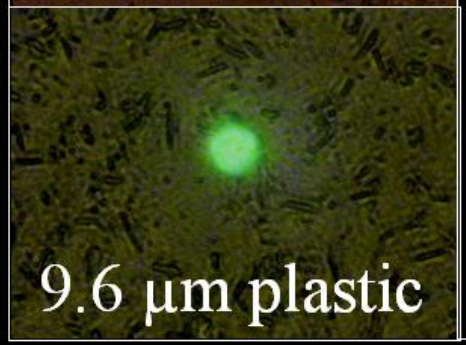
Fluorescent particles ingested by mussels

Persisted in haemolymph for 48 days, greater uptake of

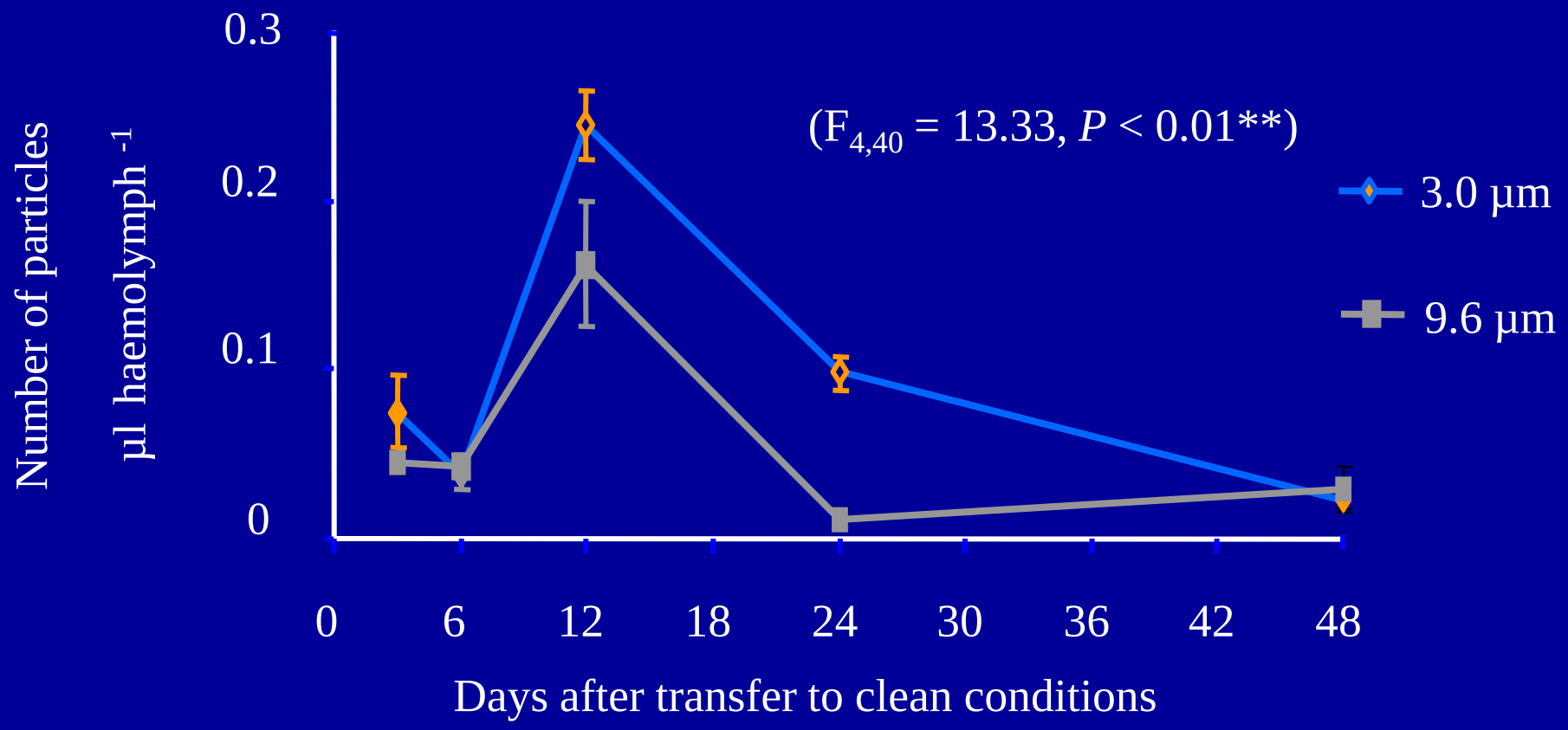
microplastic in gut cavity of *M. edulis*

Particles tracked into haemolymph





When transferred to clean conditions abundance declines



Peak abundance for both particles at day 12 and declined thereafter

Biological effects

Presence of microplastic did not reduce

- Cellular viability
- Phagocytosis
- Ferric Reducing Antioxidant Potential
- Clearance rate

Effects on debris

Plastic bags shredded by amphipods (fouled and bio degradable)

Does microplastic present a toxicological hazard?

Low OC beach

High OC beach

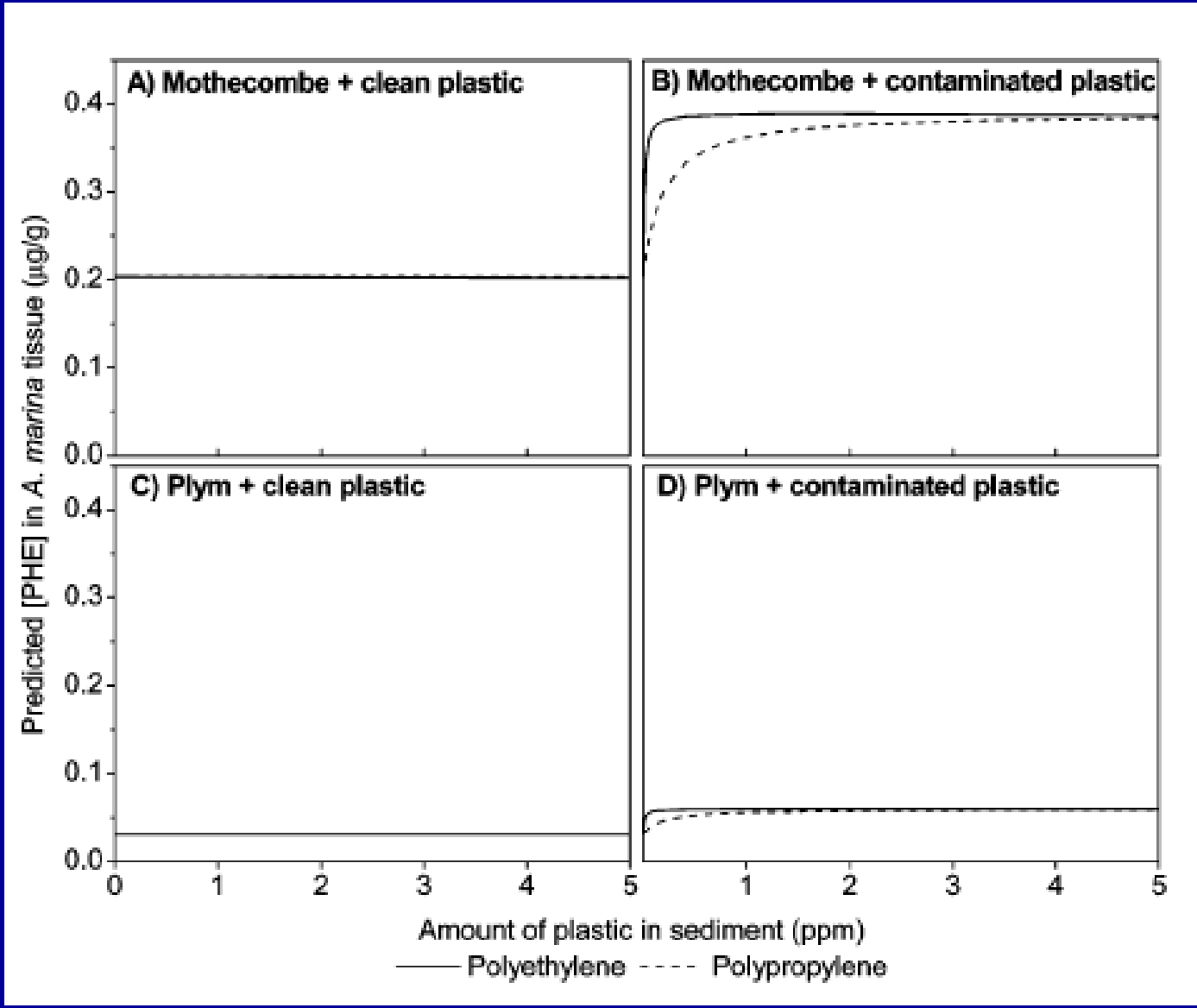
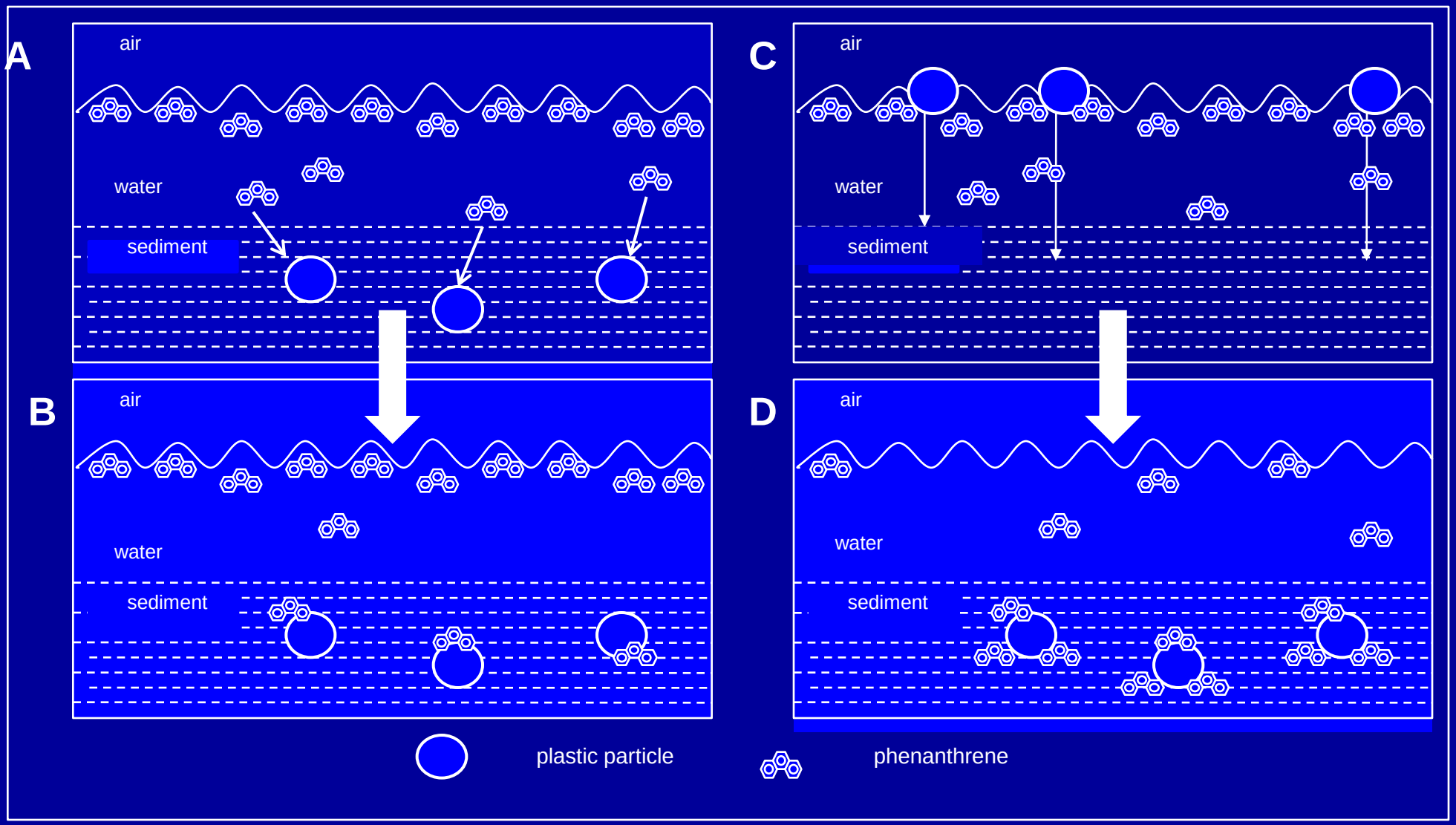


FIGURE 1. Predicted amount of phenanthrene accumulated in *A. marina* from (A) Mothecombe (low % OC) sediment with clean plastic, (B) Mothecombe sediment with plastic contaminated in the SML, (C) Plym (moderate % OC) sediment with clean plastic, and (D) Plym sediment with plastic contaminated in the SML. An enrichment factor of 61 was used for the phenanthrene concentration in the SML as compared to the bulk water (*19*). Note that when $x = 0$, the sediment contains no plastic. An expanded version (0–500 ppm) is shown in Supporting Information Figure S1.

In-vitro modelling of transport on particles of new polyethylene & polypropylene (Teuten et al. 2007)

Possible scenarios for pollutant/plastics interactions:
A – B = Sorption onto plastics in Sediments
C – D = initial enhanced adsorption onto plastics in sea-surface layers



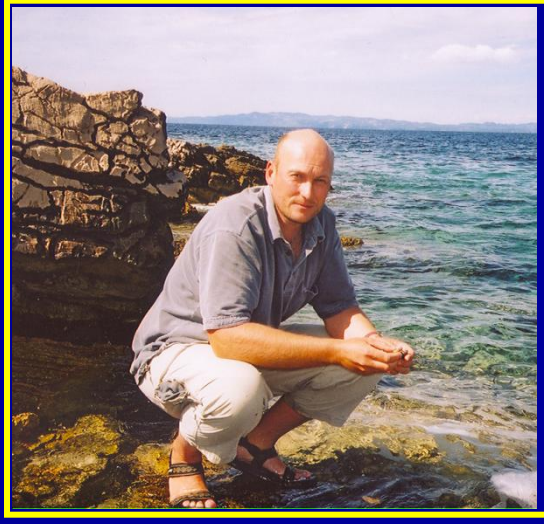
(Teuten et al. 2007)

This slide contained unpublished data on uptake of contaminants form plastics by a deposit feeding invertebrate (Thompson et al. Unpublished data)

This slide contained unpublished data on toxicological consequences of uptake of contaminants form plastics by a deposit feeding invertebrate (Thompson et al. Unpublished data)

Conclusions

- Microplastics are widespread and can be ingested
- Particles transfer from gut to haemolymphbin *Mytilus*
- Transfer influenced by size
- Particles retained but abundance declined through time
- Pollutants desorb from microplastics, in presence of gut fluids
- Context specific - many more scenarios to investigate!



Richard Thompson

Marine Biology Ecology Research Centre
University of Plymouth, UK

And to Co authors: Steven Rowland,
Tamara Galloway, Mark Browne, Stewart Niven and EmmaTeuten

Research funded by Leverhulme Trust UK

Translating scientific findings into action: California's response to plastics in the environment

Dr. Stephen B. Weisberg, Southern California Coastal Water Research Project, Costa Mesa, CA, USA

Dominic Gregorio, California State Water Resources Control Board, CA, USA

Abstract: Numerous studies have documented the increasing presence of debris in the marine environment, from derelict floating fishing gear to litter on beaches. In response, California's Ocean Protection Council passed a landmark resolution in 2007 to reduce marine debris, followed by a draft implementation plan in 2008. The implementation plan, as well as actions being undertaken or considered by local jurisdictions, fall into five general strategies: 1) Regulatory controls on the discharge of plastic debris; 2) Public education and behavior modification; 3) Change the packaging strategy; 4) Remove debris from the environment; and 5) Monitor to assess program effectiveness. These strategies reflect effective translation of science into management, but most of the actions focus on reducing the amount of large debris. In part this is because the management actions for large debris are easier to implement, but it also reflects our lesser scientific knowledge about the sources and effects of microdebris. Here we discuss the interface between scientific findings and management action, highlighting the scientific needs for microdebris in that context.

Stephen Weisberg, PhD, is Executive Director of the Southern California Coastal Water Research Project (SCCWRP) where he specializes in the design and implementation of environmental monitoring programs. He Chairs the Southern California Bight Regional Monitoring Steering Committee and is on the Governing Boards of the California Ocean Science Trust and the Southern California Coastal Ocean Observing System. He serves on advisory committees for numerous programs, including the California Ocean Protection Council, California's Clean Beach Task Force the University of Southern California Sea Grant Program, the Alliance for Coastal Technology and the Hollings Laboratory Oceans and Human Health Program. Dr. Weisberg received his undergraduate degree from the University of Michigan and his Ph.D. from the University of Delaware.

TRANSLATING SCIENTIFIC FINDINGS INTO ACTION: CALIFORNIA'S RESPONSE TO PLASTICS IN THE MARINE ENVIRONMENT

Stephen B. Weisberg
Southern California Coastal Water Research Project Authority

Dominic Gregorio
California State Resources Control Board

STARTING POINT

- Numerous marine debris studies have been conducted in California
  - Beach
  - Ocean bottom
  - Water column
  - Stream

- These studies have translated into considerable management action
  - Most actions are focused on large debris

- Focus of this talk on the relation between science and management action

ORANGE COUNTY BEACH STUDY

- Initiated in 1998 to assess quality of beach cleanup day data
- 43 stratified random sites
- 25-yard segment surveyed at each site
  - Multiple passes to assess effectiveness
- Sand was sieved at each site
  - Originally looking for cigarette butts

Debris type	Bight 98	Coastal Cleanup Day- 1998
Pre-production plastic pellets	105,160,101	
Foamed plastic		
Hard plastics		
Cigarette butts		
Paper		
Wood		
Metal		
Glass		
Rubber		
Pet and bird dr		
Cloth		
Other		
Total with pelle		
Total without p		

TRAWL STUDIES

- Conducted every five years as part of a regional fish survey
  - ≈300 random sites in southern California
- Ten minute tows with 3.8 cm mesh net
- Debris found in 70% of the trawls

WATER COLUMN STUDIES

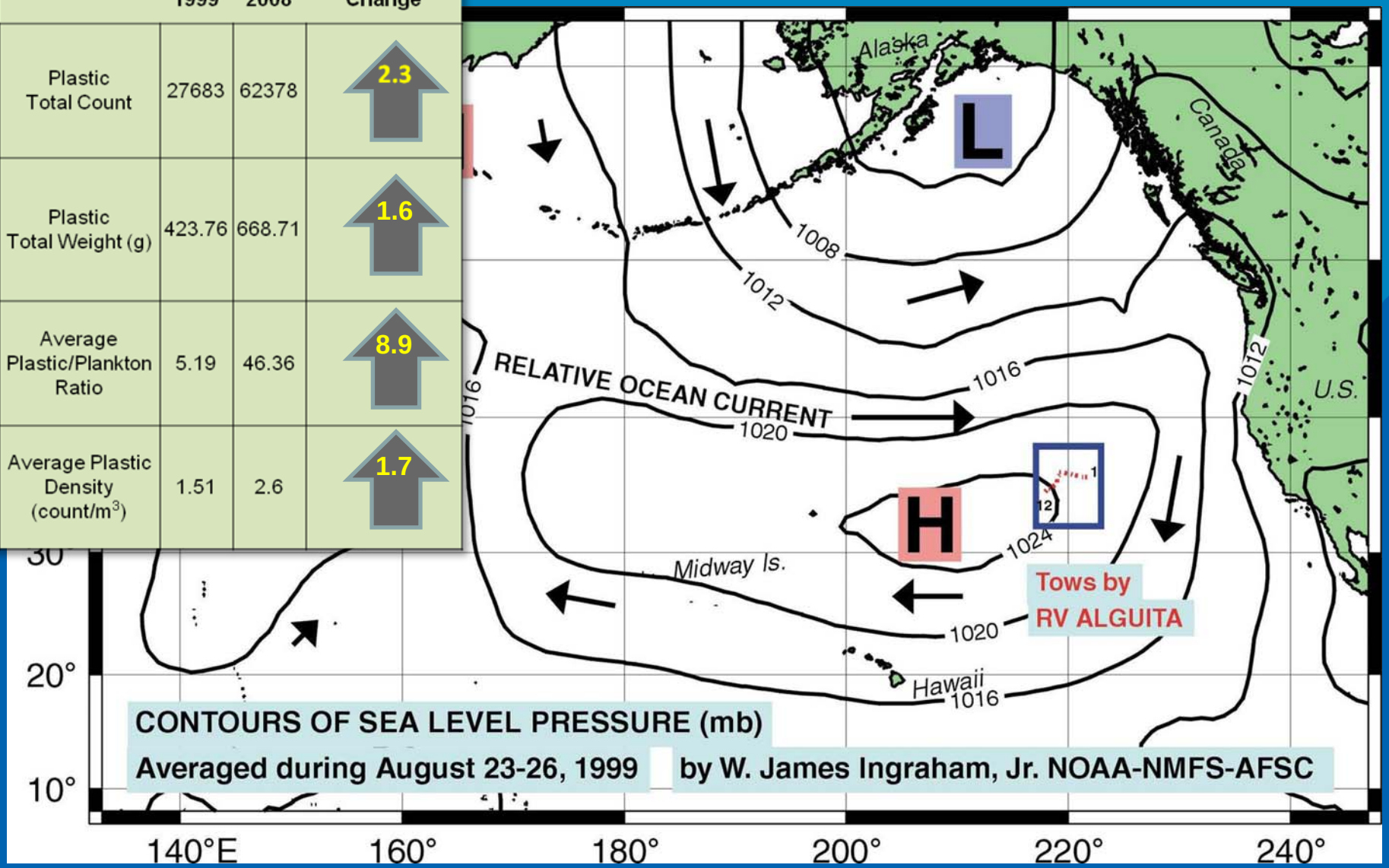
- **Three study locations**
  - North Pacific gyre
  - Offshore of San Gabriel River
  - Offshore of Ballona Creek
- **Towed a 0.9 m manta net for 0.5km**
  - 333 um mesh
- **Number/ dry weight of plastic and plankton recorded**

WATER COLUMN DEBRIS CONCENTRATION

	Average Debris		Plastic:plankton ratio (mass)	
	(g/m³)	(pieces/m³)	All Debris	Debris <4.75 mm
Ballona Creek	0.003	3.92	1.4:1	0.3:1
San Gabriel River	0.002	7.25	2.5:1	0.6:1
North Pacific Gyre	0.034	2.23	6.1:1	0.3:1

Comparison of 1999 and 2008 in the North Pacific Gyre

	1999	2008	Change
Plastic Total Count	27683	62378	2.3
Plastic Total Weight (g)	423.76	668.71	1.6
Average Plastic/Plankton Ratio	5.19	46.36	8.9
Average Plastic Density (count/m^3)	1.51	2.6	1.7

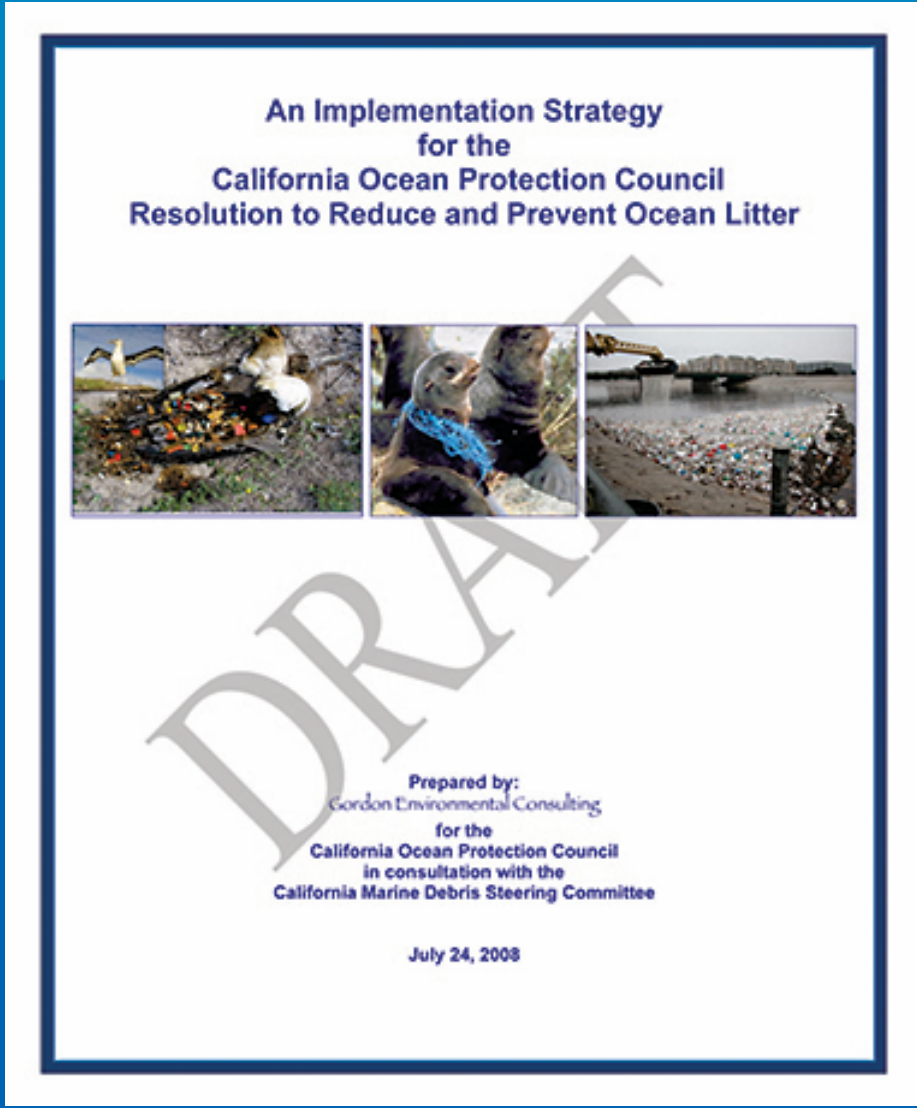


STREAM STUDIES

- Nets placed at downstream locations in several river systems
- Inspection and sampling downstream of industrial facilities
- Primary Findings: microplastics are abundant in streams flowing to the ocean
  - They were particularly abundant near industrial facilities
  - Many poor housekeeping practices observed at manufacturing facilities

CALIFORNIA IS TAKING ACTION

- Regulatory controls on discharges
- Public education and behavior modification
- Change the packaging strategy
- Debris removal
- Monitoring to assess effectiveness



An Implementation Strategy
for the
California Ocean Protection Council
Resolution to Reduce and Prevent Ocean Litter

DRAFT

Prepared by:
Gordon Environmental Consulting
for the
California Ocean Protection Council
in consultation with the
California Marine Debris Steering Committee

July 24, 2008

REGULATORY CONTROL OF DISCHARGE

- Amend Water Quality Standards
  - State Water Board is amending the California Ocean Plan to classify debris as a pollutant to be controlled
  - Will lead to inclusion of debris controls in stormwater permits

- 303(d) listings and TMDLs
  - California currently has 41 water bodies listed as impaired by debris
  - Los Angeles Regional Water Board has developed eight trash TMDLs, but all focused on debris >5 mm

- **Assembly Bill 258 initiates a statewide program to reduce industrial discharge of plastic pellets**
  - The Los Angeles Regional Water Board has initiated enforcement against 20 manufacturing facilities
  - Industry initiated Operation Clean Sweep, a BMP program to control discharge from manufacturing facilities

Operation Clean Sweep

The plastics industry is committed to its role as an environmental steward. Operation Clean Sweep was developed to prevent the release of resin pellets into the environment.

- Zero Pellet Loss Approach
- BMP Manual and Training Program
- 134 participating companies, 55 in CA
- http://www.opcleansweep.org/default.asp

PUBLIC EDUCATION AND BEHAVIOR MODIFICATION

- **Public information campaigns**
  - California State Water Board spent $5 million on “Erase the Waste” public education campaign
  - Caltrans has a “Don’t Trash California” campaign
  - Solid waste management practices have been added to the Clean Marina Program
- **Prohibitions and enforcement of litter laws**
  - Caltrans is partnering with the Highway Patrol
  - State Parks prohibits smoking on state beaches

CHANGE THE PACKAGING STRATEGY

- **Institute product prohibitions**
  - Five municipalities have limitations or bans on plastic grocery bags
  - More than 20 municipalities have instituted ordinances on polystyrene use
- **Fees on plastic products**
  - AB 2058 - The legislature is considering a 25 cent fee on plastic grocery bags
- **Develop alternatives to plastic**
  - The Department of Toxic Substances Control is researching commercialization potential for biodegradable “plastics”
- **Determine which plastic additives pose a threat**
  - The Office of Environmental Health Hazards Assessment is assessing which additives are most toxic

REMOVE DEBRIS FROM THE ENVIRONMENT

- **Facilitate recycling**
  - Expand the number of items with redemption value
  - AB 2449 requires grocery stores to take back plastic grocery bags
- **Beach trash cleanup efforts**
  - Expand the Coastal Commission adopt-a-beach program
- **Derelict fishing gear removal**
  - OPC funded “Sea Doc” program has conducted pilot derelict fishing gear cleanups

MONITOR TO ASSESS PROGRAM EFFECTIVENESS

- **Scientific Monitoring**
  - Institute a baseline monitoring program to evaluate effectiveness of AB258 implementation
- **Promote quantification of cleanup efforts**
  - Make the adopt-a-beach cleanup data more consistent and comparable to scientific studies

WHAT FACTORS HAVE FACILITATED ACTION?

- **Solid scientific foundation**
- **Effective advocate**
  - Algalita Foundation has used the science to create awareness
  - Augmented science with pictures and videos
  - Engaged the press
- **Accessible governance structure**
  - California Ocean Protection Council provides a forum for establishing priorities and facilitating cross-agency coordination
  - Place your associates in the right positions!
- **Neutral scientific translator**
  - Managers need an entity to vet the advocate's position

IMPRESSIVE LIST OF ACTIVITIES, BUT MOSTLY FOCUSED ON LARGE DEBRIS

- Large material is easier to address
  - Filtration units
  - Nets
- Trickle down theory
  - Much of the small stuff is disintegrated big stuff
- Association with beneficial use
  - Debris on the beach
  - Tangled animals
- Where is that smoking gun for the small stuff?
  - Documentation of runoff from industrial facilities led to AB258

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WHAT WE ARE TELLING MANAGERS ABOUT EFFECTS OF MICROPLASTICS

- **Plastics interfere with proper nutrition**
  - Blockage of feeding structures or artificial satiation
  - Pictures tell a thousand words for the big stuff
  - Where is the proof for microdebris?
- **Contaminants adhere to plastics and poison animals**
- **Many unproven links in the contaminant chain**
  - POPs adhere to plastics
  - POPs disassociate from plastics in the animal intestine
  - They accumulate to levels that are high enough to cause harm
- **Burden of proof is on us!**
  - We as scientists need to establish dose-response relationships
  - How clean does it need to be to protect beneficial use?

CONTINOUS DEFLECTIVE SEPARATION (CDS)

ESTIMATING DEBRIS TOTALS FOR ORANGE COUNTY

Debris Type	Abundance	Weight (lbs)
Pre-production plastic pellets	105,161,101	4,780
Foamed plastics	742,296	1,526
Hard plastics	642,020	7,910
Cigarette butts	139,447	344
Paper	67,582	870
Wood	27,919	4,554
Metal	23,500	3,015
Glass	22,195	1,944
Rubber	10,742	817
Pet and bird droppings	9,388	17
Cloth	5,949	1,432
Other	10,363	401
Total	106,862,502	27,611

SESSION III: IMPACTS OF SMALL PLASTIC DEBRIS EXPOSURE TO PERSISTENT ORGANIC POLLUTANTS

Effect of sorbent particles on the bioaccumulation of persistent organic pollutants in sediments

Dr. Upal Ghosh, University of Maryland Baltimore County, Baltimore, MD, USA

Abstract: Our recent work provides new understanding of contaminant binding through direct microscale determination of contaminant association with sediment particle types. We investigated the roles of different types of natural and anthropogenic organic particulates in impacted sediments (coal, soot, charcoal, wood, coal tar pitch, and humic materials) and explored how predominant association of contaminants with certain types of organic matter may affect overall bioavailability. In our work with sediment from several urban locations across the country, we find that the majority of hydrophobic contaminants such as PAHs and PCBs are strongly bound to carbonaceous particles. We also find that PAHs bound to carbonaceous particles are resistant to desorption, microbial biodegradation, and bioaccumulation by organisms. Our current work extends this understanding by demonstrating how the addition of low-cost sorbents such as activated carbon, may sequester persistent organic contaminants, and reduce contaminant availability, exposure, and accumulation in sediment-dwelling organisms. We propose that addition of activated carbon to PCB contaminated sediment may be an effective in-situ stabilization method to reduce contaminant availability to biota and surrounding water. We are now testing this approach in two pilot-scale technology demonstrations, one in a tidal mudflat, and the other in a river environment. This talk will focus on the role of strong sorbent particles on contaminant bioavailability in sediments and also explore the impact of plastic debris on contaminant bioavailability to marine organisms.

Upal Ghosh, PhD, is an associate professor at the department of Civil and Environmental Engineering, University of Maryland Baltimore County (UMBC). His research explores fundamental process mechanisms that control organic contaminant fate in soils, sediments, and aquatic environments. His research uses multidisciplinary tools to investigate exposure and bioavailability of organic contaminants to organisms. The new understanding is used to develop novel remediation technologies, site-specific risk assessment, and remediation goals. Dr. Ghosh is currently involved in pilot-scale technology demonstrations of in-situ remediation of PCB-impacted sediments. The technology is based on contaminant binding and bioavailability reduction through the amendment of activated carbon tosediments.

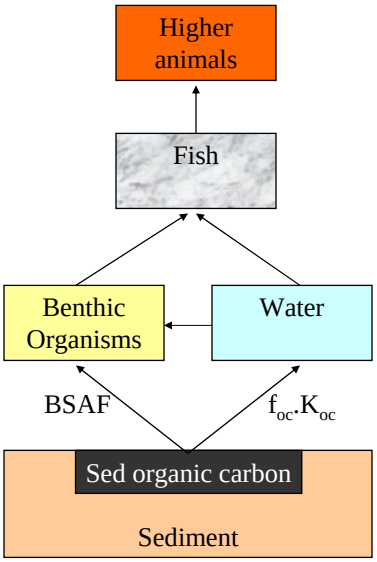
Dr. Ghosh has a M.S. and Ph.D. in Civil and Environmental Engineering from the University at Buffalo, and a B.Tech. in Chemical Engineering from the Indian Institute of Technology, Bombay. Before joining UMBC, Dr. Ghosh worked at Carnegie Mellon University as a post doctoral fellow and at Stanford University as a research associate and lecturer.

Effect of Sorbent Particulate Amendments on PCB Bioavailability in Sediments

Upal Ghosh, University of Maryland Baltimore County

International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris
Tacoma, WA

Link geochemistry and bio-uptake

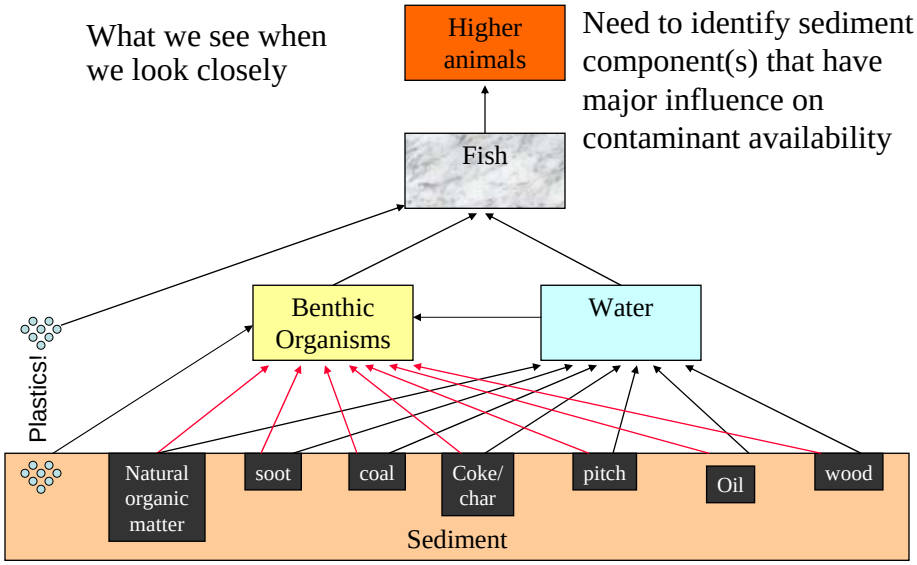


Traditional view

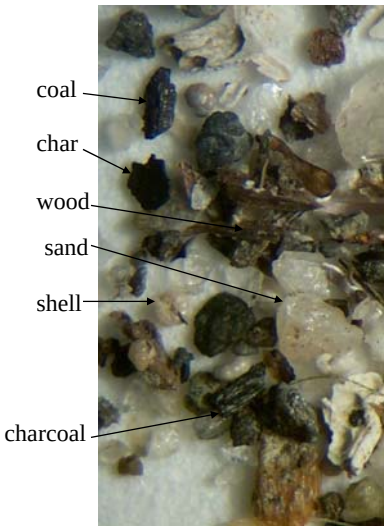
A more accurate description?

What we see when we look closely

Need to identify sediment component(s) that have major influence on contaminant availability



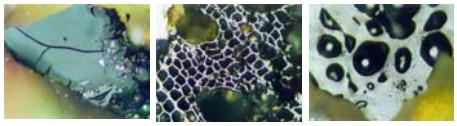
Contaminant distribution in sediment particles



San Francisco Bay Sed (63-250 µm)

- Sediment contains sand, silt, clays, charcoal, wood, char, coal, & shells
- Lighter particles (charcoal, wood, coal, shells) can be separated by density at specific gravity of ~1.8
- Coal petrography analyses identify carbonaceous particles
- PCBs and PAHs largely associated with carbonaceous particles

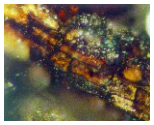
Petrography images

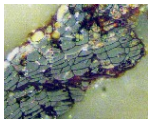


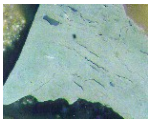
coal charcoal coke

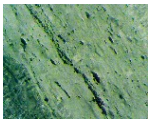
Petrography analysis:

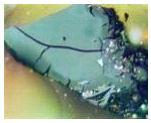
Identification of particulate organic carbon in sediments


wood

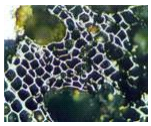

lignite

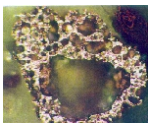

bituminous coal

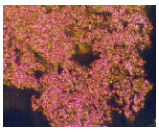

anthracite coal

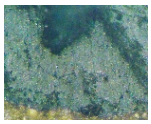

oxidized coal

coke


charcoal

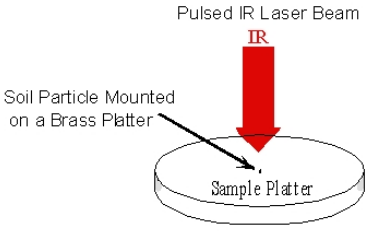

cenosphere

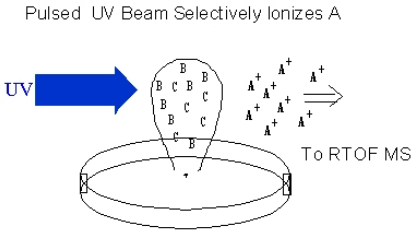

soot carbon


coal tar pitch

Microprobe Laser Desorption Laser Ionization Mass-Spec (μL^2MS)

(A) Laser Desorption of Neutral Molecules **(B) Laser Ionization**

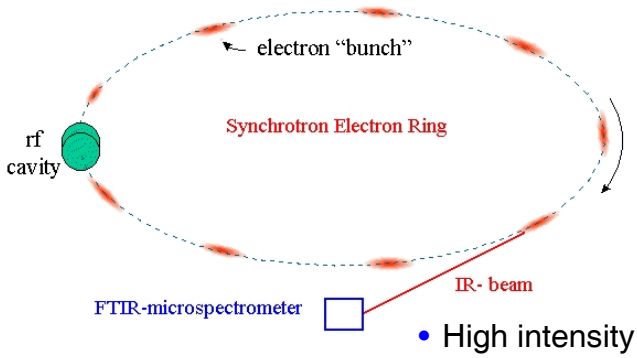




Chemistry department, Stanford University

Analysis spot size ~ 40 μm

FTIR Microspectroscopy Using Synchrotron Light Source



- High intensity beam
- Small spot size ~ 5 μm
- Identification of organic matter
- Time resolved spectroscopy

NSLS, Brookhaven National Lab
ALS, Lawrence Berkeley National Lab

FTIR Microspectrometer at Lawrence Berkeley National Lab

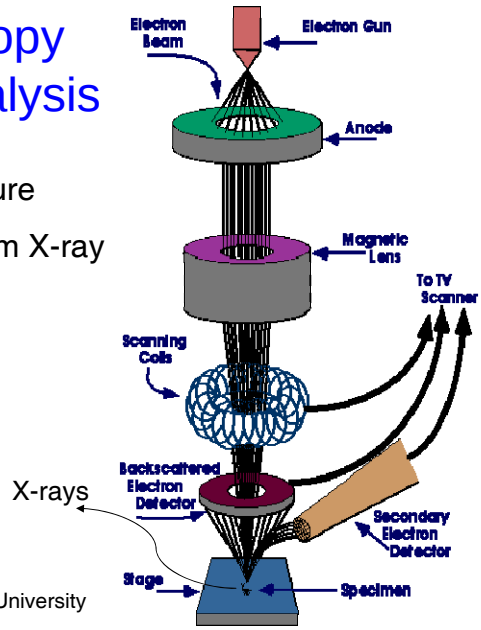
Nicolet 760 FTIR Bench

Nic-Plan IR Microscope

Video monitor and micro-stage controller

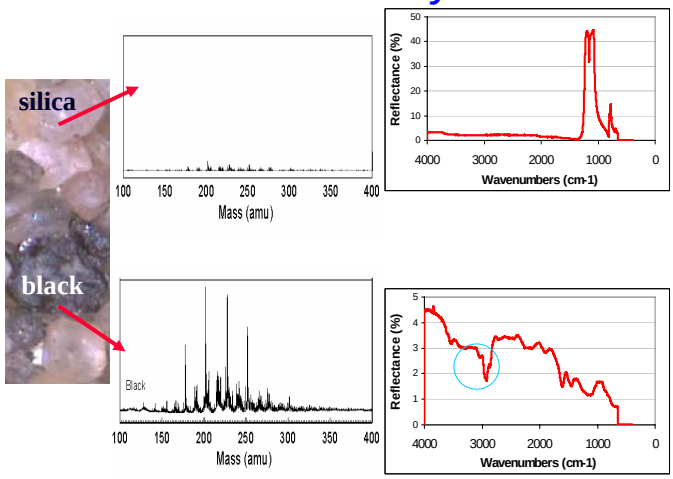
Electron Microscopy with Elemental Analysis

- investigation of fine structure
- elemental composition from X-ray analysis



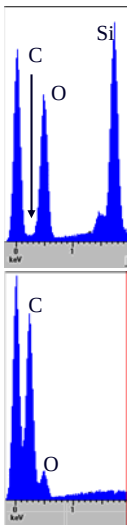
Material Science Dept, Carnegie Mellon University

Coincident PAH, organic & elemental analysis



PAH Mass Signal

IR Reflectance

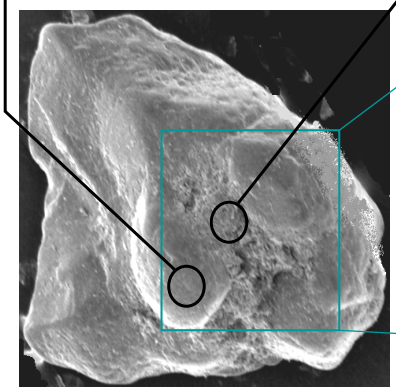


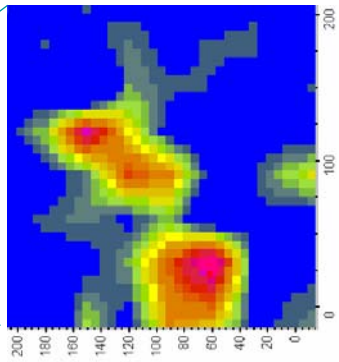
Elemental Comp.

Organic matter spots with PAHs on silica particle surface

Bare silica, low PAH

Clay, OM, high PAH





SEM photograph

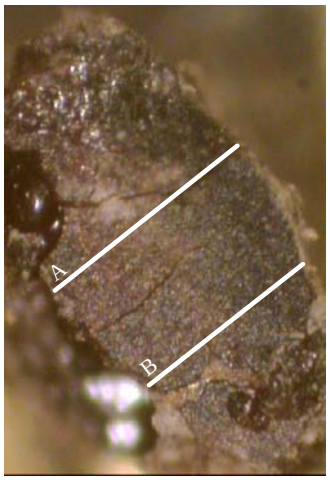
Red indicates IR absorbance for C-H

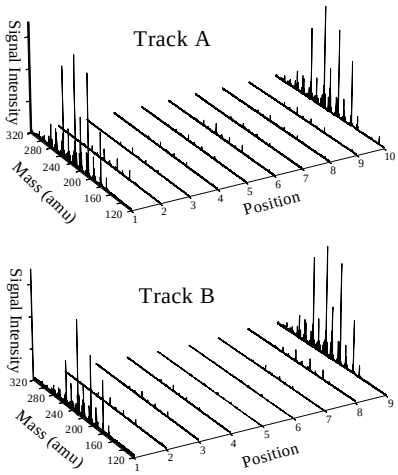
Particle sectioning for interior analysis

Slicing sediment particle with a diamond knife using a cryomicrotome at -150°C

Before and during cutting

PAH measurement inside particles

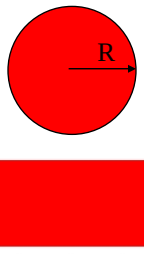




Sectioned surface of a coal-derived particle

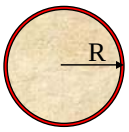
Spot PAH measurement along tracks A & B using μL^2MS

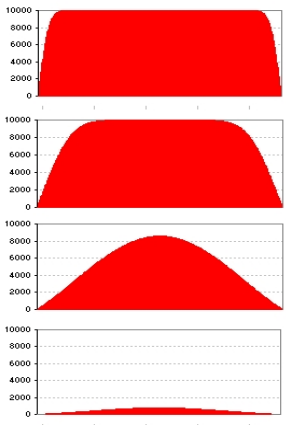
Spatial conc. profile during desorption

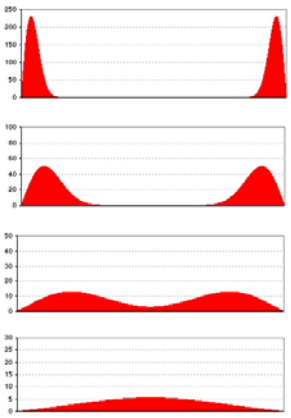


Fully penetrated sphere

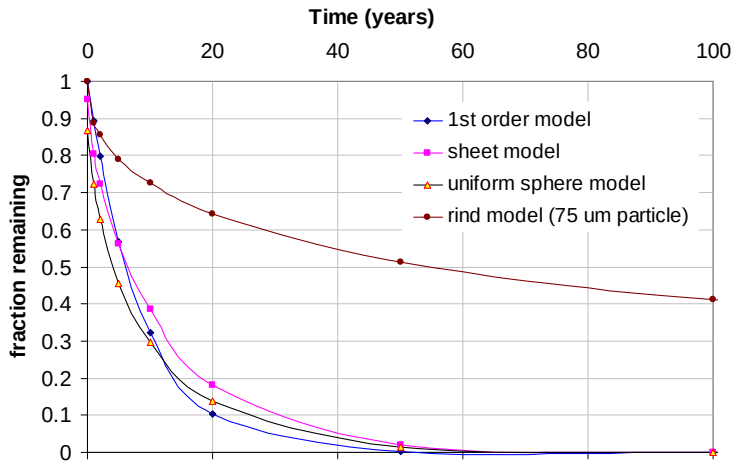
Partially penetrated sphere



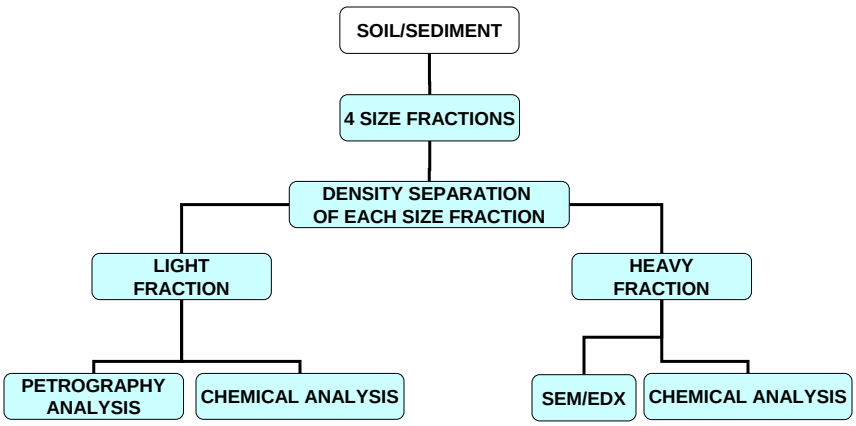




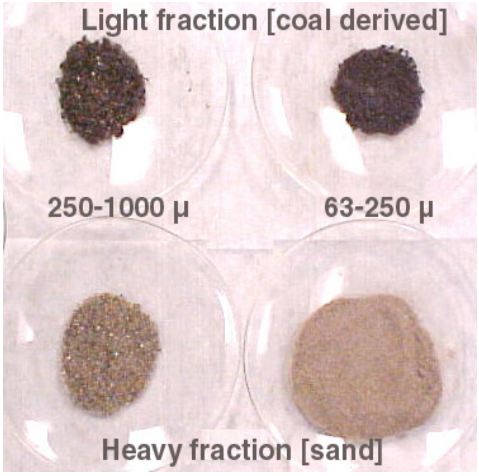
Simulated long term release of PAH MW 202 from coal into an infinite sink



Size and Density Fractionation of Soil/Sediment Particles



Sediment Fractions by Size and Density

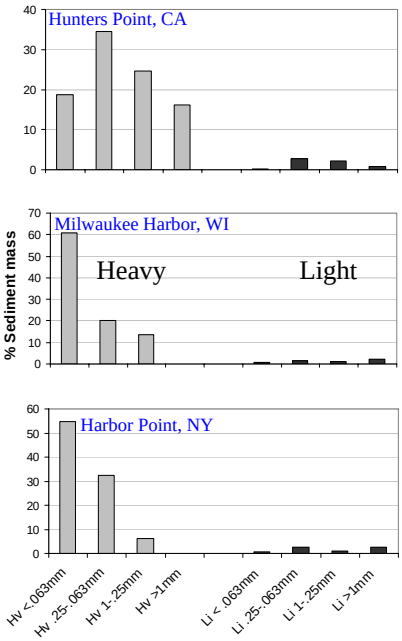


Two density fractions in each size fraction:

Light:
organic particles

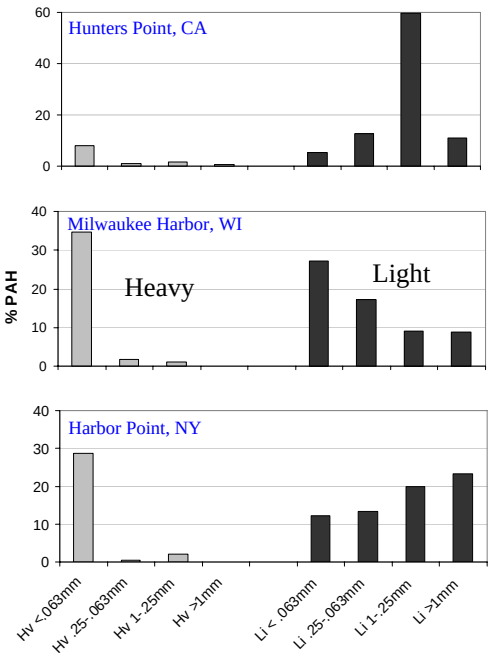
Heavy:
sand/silt/clays

Mass Distribution



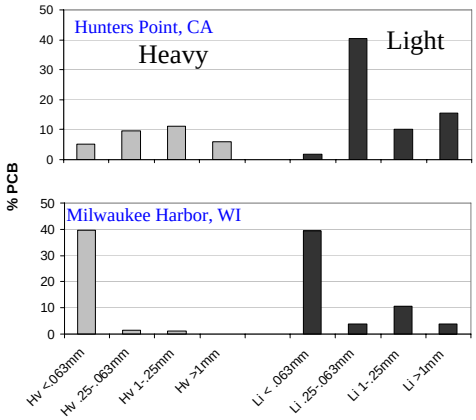
Three sites show 5-7% wt. lighter density carbonaceous matter

PAH Distribution



60-90% PAHs associated with lighter density carbonaceous matter

PCB Distribution



60-70% PCBs associated with lighter density carbonaceous matter

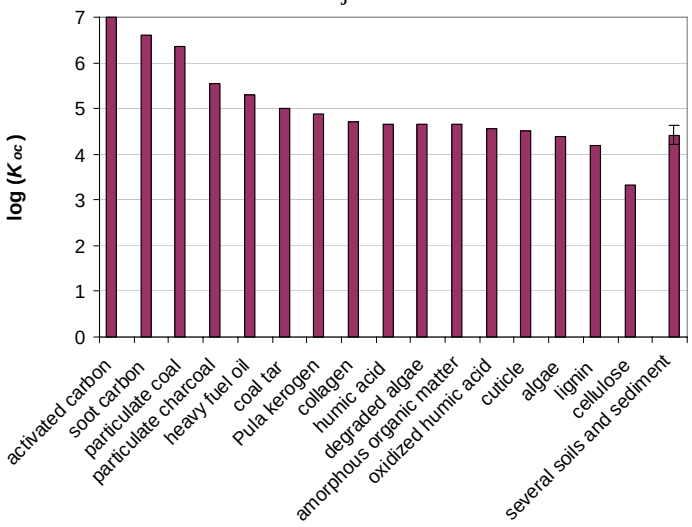
Relevant Publications

- Microscale Location, Characterization, and Association of Polycyclic Aromatic Hydrocarbons on Harbor Sediment Particles. U. Ghosh, R.G. Luthy, J.S. Gillette and R.N. Zare. ***Environ. Sci. & Technol***., 34, 1729-1736, 2000.
- Particle-scale Investigation of PAH Desorption Kinetics and Thermodynamics from Sediments. U. Ghosh, J.W. Talley, R.G. Luthy, ***Environ. Sci. & Technol***., 35, 3468-3475, 2001.
- PCB and PAH Speciation Among Particle Types in Contaminated Sediments and Effects on PAH Bioavailability. U. Ghosh, J. Zimmerman, R.G. Luthy. ***Environ. Sci. & Technol***., 37, 2209-2217, 2003.
- Role of Weathered Coal Tar Pitch in the Partitioning of Polycyclic Aromatic Hydrocarbons in Manufactured Gas Plant Site Sediments. M.F. Khalil, U. Ghosh, J.P. Kreitinger. ***Environ. Sci. Technol***. In Press. 2006.

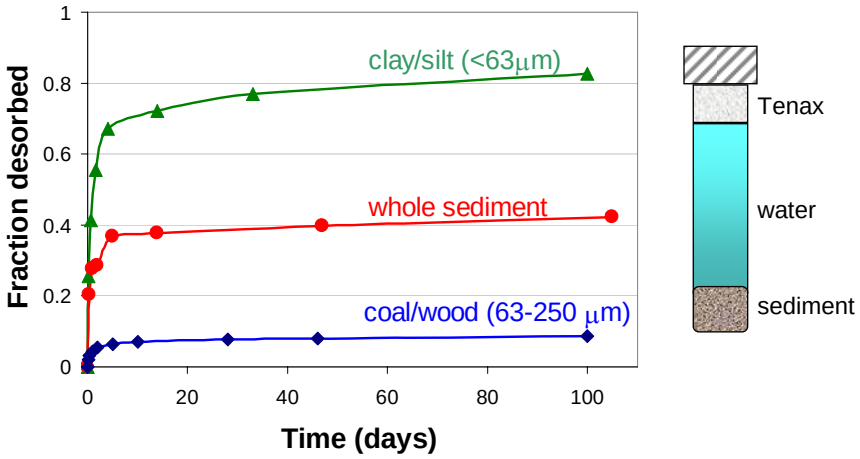
Sediment-water partitioning of phenanthrene

$C_s = C_{aq} \cdot K_{oc} \cdot f_{oc}$

Need to identify sediment component(s) that have major influence on contaminant availability

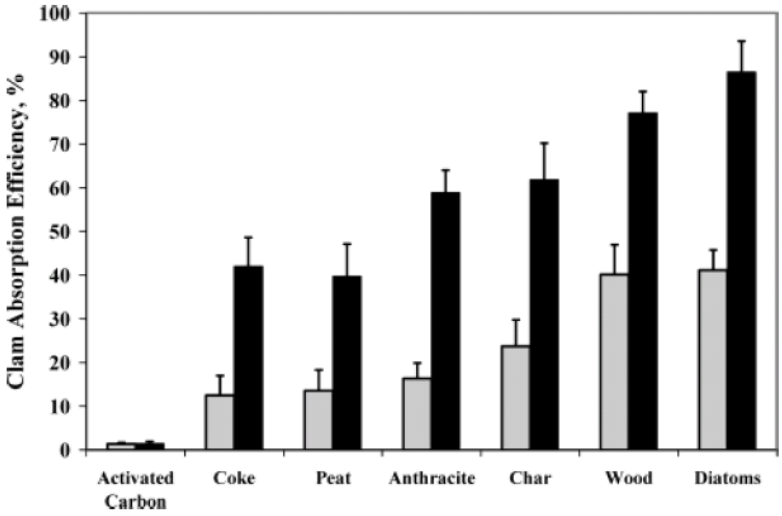


PAH release from sediment components



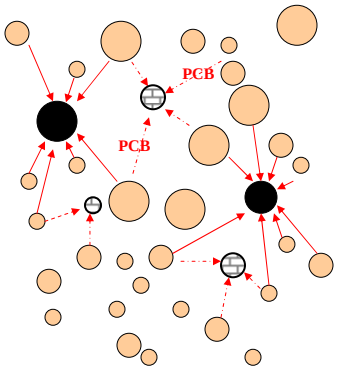
- **High PAH availability from clay/silt**
- **Low PAH availability from coal/wood**

PCB absorption efficiency in clam gut



From: McLeod et al. Environ. Sci. Technol. 2004

PCB bioavailability control



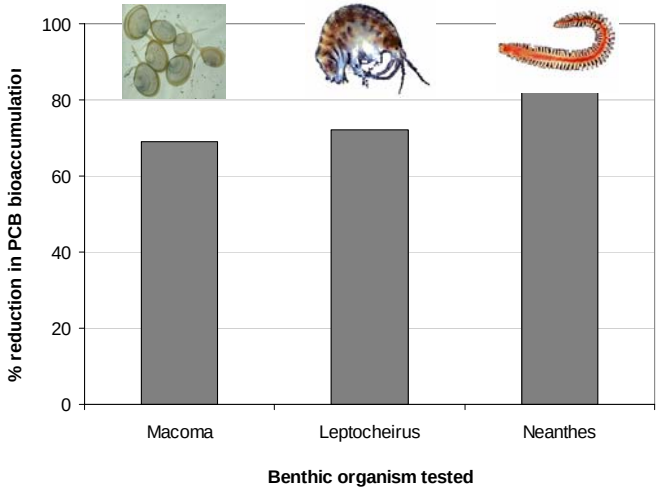
Sediment particles with PCBs
Natural carbonaceous particles
Introduced AC particles

- Bioavailability of PCBs, depends on sorbent particle type.
- Natural black carbon particles sequester PCBs, reduce bioavailability
- AC can alter PCB bioavailability.
- New strategy for sediment management using in situ stabilization
- Bioavailability reduction demonstrated for PCBs, PAHs, DDT and metals.

Published papers:

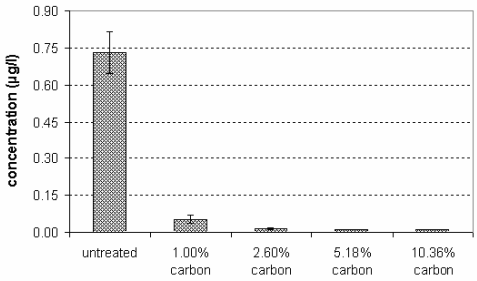
Ghosh et al., ACS Symp. paper, vol 43, 2, 2003
Zimmerman et al., ES&T, 2004
Millward et al., ES&T, 2005.
McLeod et al., ES&T, 2005
Werner et al., ES&T, 2006
Cornelissen et al., ES&T, 2006
Sun & Ghosh, ES&T 2007
Cho et al, MER 2007

PCB Bioaccumulation Reduction

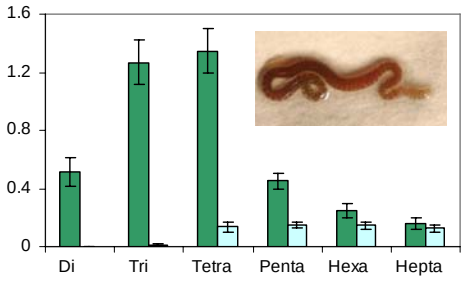


Activated carbon addition reduces PCB bioavailability in sediments

Lumbriculus lipid vs. sediment aqueous PCB

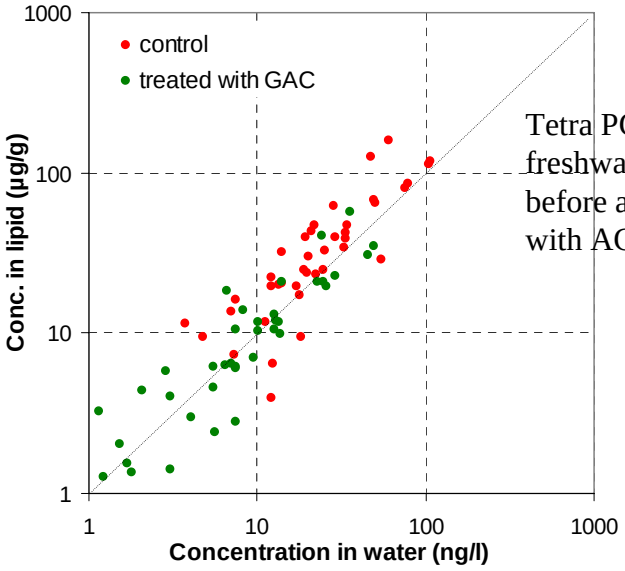


Pore water PCB concentration from Grasse River sediment with different doses of activated carbon



Amendment of sediment with 2.5% activated carbon reduced PCB biouptake in a freshwater oligochaete

Lumbriculus lipid vs. sediment aqueous PCB



Tetra PCB congeners in 3 freshwater sediments before and after treatment with AC

Demonstration Project at Hunters Point, CA

(Participants: Stanford University, UMBC, ERDC, Navy)

Aquamog with roto-tiller arm

(Aquatic Environments, Inc., Concord, CA)

Injection system

(Compass Environmental, Inc., Stone Mountain, GA)

Application in the Grasse River

Mixed Tiller (75' x 100')

Unmixed (50' x 50')

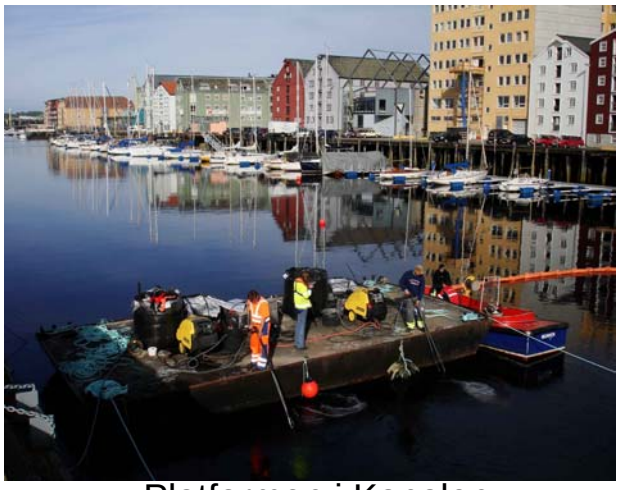
Tine Sled (50' x 60')

Initial testing area (50' x 100')

- L-shaped silt screen to minimize suspended particle transport
- Equipment mobilized on barges
- Target dose of activated carbon = 2.5% in surficial sediments
- No measurable change in water-column PCBs downstream
- Post-treatment monitoring to continue for 2-3 years

Demonstration Project at Trondheim Harbor, Norway

(Participants: Norwegian Geotechnical Institute, Stockholm University, and UMBC)



Platformen i Kanalen

- 2000 kg AC applied in a 2000 m^2 plot
- Application without mixing in May 2007
- Contaminants of interest: PCBs, PAHs, PBDEs, and DDT
- Performance monitoring in 08/09
- Distribution of AC, bioaccumulation tests, aqueous concentrations using POM-SPE

In-Situ PCB Bioaccumulation Studies

In-river deployment of field exposure cages with *L. variegatus* for baseline study using a modified ASTM draft method (Burton et al. 2005)

Global rates of production

	Production (Million T/y)	Phenanthrene Kd (L/kg)
Plastics (*Ref?*)	230	10^4-10^5
Coal & lignite (*World Coal Institute data*)	6,276	10^6-10^7
Natural BC (*Kuhlbusch, 1998*)	40-120	10^5-10^6
Fossil burning BC (*Penner et al., 1993*)	12-24	10^6-10^7
Ocean primary production of carbon (*Ocean Primary Prod. Study, Rutgers Univ*)	46,000	10^4-10^5

Future work

- Look at exposure pathways comprehensively, not just microplastics
- Describe partitioning of POPs in plastics better. Near-surface absorption may dominate due to low polymer diffusivity
- Evaluate assimilation efficiency of POPs sorbed on microplastics

Stormwater Trash Collection in Baltimore City

Acknowledgements

UMBC Graduate Students and post docs:

Xueli Sun; Barbara Beckingham; Adam Grossman; Jeff Thomas; Piuly Paul, Jennifer Jerschied, Seokjoon Kwon, Sonja Fagervold

Sponsors:

US Dept of Defense, SERDP/ESTCP Programs; USEPA Great lakes National Program Office; Alcoa, USEPA SBIR program; National Institutes of Health, Norwegian Research Council

Current and Past Collaborators:

G. Cornelissen, D. Werner; C.A. Menzie; Cindy Gillmour; R.G. Luthy; Y-M Cho, T.S. Bridges

Ghosh research group at UMBC

International Pellet Watch: Global distribution of persistent organic pollutants (POPs) in marine plastics and their potential threat to marine organisms

Hideshige TAKADA, Laboratory of Organic Geochemistry, Tokyo University of Agriculture and Technology, Tokyo, JAPAN

Abstract: Beached resin pellet samples collected at 30 locations from 17 countries were analyzed for PCBs, DDTs, HCHs, PAHs, and hopanes. PCB concentrations in the polyethylene pellets were highest on US coasts (100 - 500 ng/g), followed by western European countries (e.g., U.K. and Netherlands) and Japan (50 - 100 ng/g), whereas lower in tropical Asia, southern Africa and Australia (5 – 50 ng/g). The spatial pattern was well correlated with that of the monitoring results of mussel watch, indicating that concentrations of hydrophobic contaminants in the plastic pellets reflect the pollution status of the coastal environments. DDTs showed high concentrations on the west coast of USA (~300 ng/g) and Vietnam (~200 ng/g). In Vietnam, DDT was predominant over its metabolites (DDE and DDD), suggesting current usage of the pesticide. High concentrations of HCHs were detected in the pellets from southern Africa (~30 ng/g), whereas HCHs showed trace concentrations in the other areas in the world (~ 1 ng/g or lower). This suggests current usage of the pesticide in southern Africa. Hopanes, biomarker of petroleum pollution, were detected in all the pellet samples collected across the world at μg/g level, indicating ubiquitous petroleum pollution. PAHs were significantly detected at several locations and they were rich in alkyl homologs, indicating the dominance of petrogenic origin over pyrogenic one. We also analyzed plastic fragments (i.e. scraps of consumer products) from the central gyre of the Pacific and a Japanese coast for the organic micropollutants. In addition to the hydrophobic organic pollutants such as PCBs and PAHs, additive-derived chemicals such as bishphenol A and nonylphenols were detected in the plastic fragments. Higher concentrations (20 – 40 ng/g) of brominated flame retardants, PBDEs, were detected in the plastic fragments from the central gyre than the Japanese coast. They were rich in BDE183 which is the major component of Octa BDEs, indicating contribution of the additives. To examine potential transfer of the plastic-associated contaminants to sea birds which ingest the marine plastics, a feeding experiment was conducted and contaminated plastic resin pellets were fed to Streaked Shearwater chicks. Analysis of PCBs in preen gland oil excreted from the sea bird suggested that transfer of lower-chlorinated congeners from the plastics to the sea bird.

Hideshige TAKADA, PhD, is an organic geochemist studing the behaviors of organic micropollutants in aquatic environments. He was born in Tokyo, Japan, in 1959. He obtained a PhD from Tokyo Metropolitan University in 1989, and then studied at Woods Hole Oceanographic Institution with Dr. John Farrington from 1990-1991. He is a professor in the Laboratory of Organic Geochemistry (LOG) in Tokyo University of Agriculture and Technology. His lab discovered a range of organic micropollutants in marine plastics in 2001. Since then they have been conducting several researches on organic micropollutants in environmental plastics including "International Pellet Watch."

International Pellet Watch : Global distribution of persistent organic pollutants (POPs) in marine plastics and their potential threat to marine organisms

Hideshige TAKADA

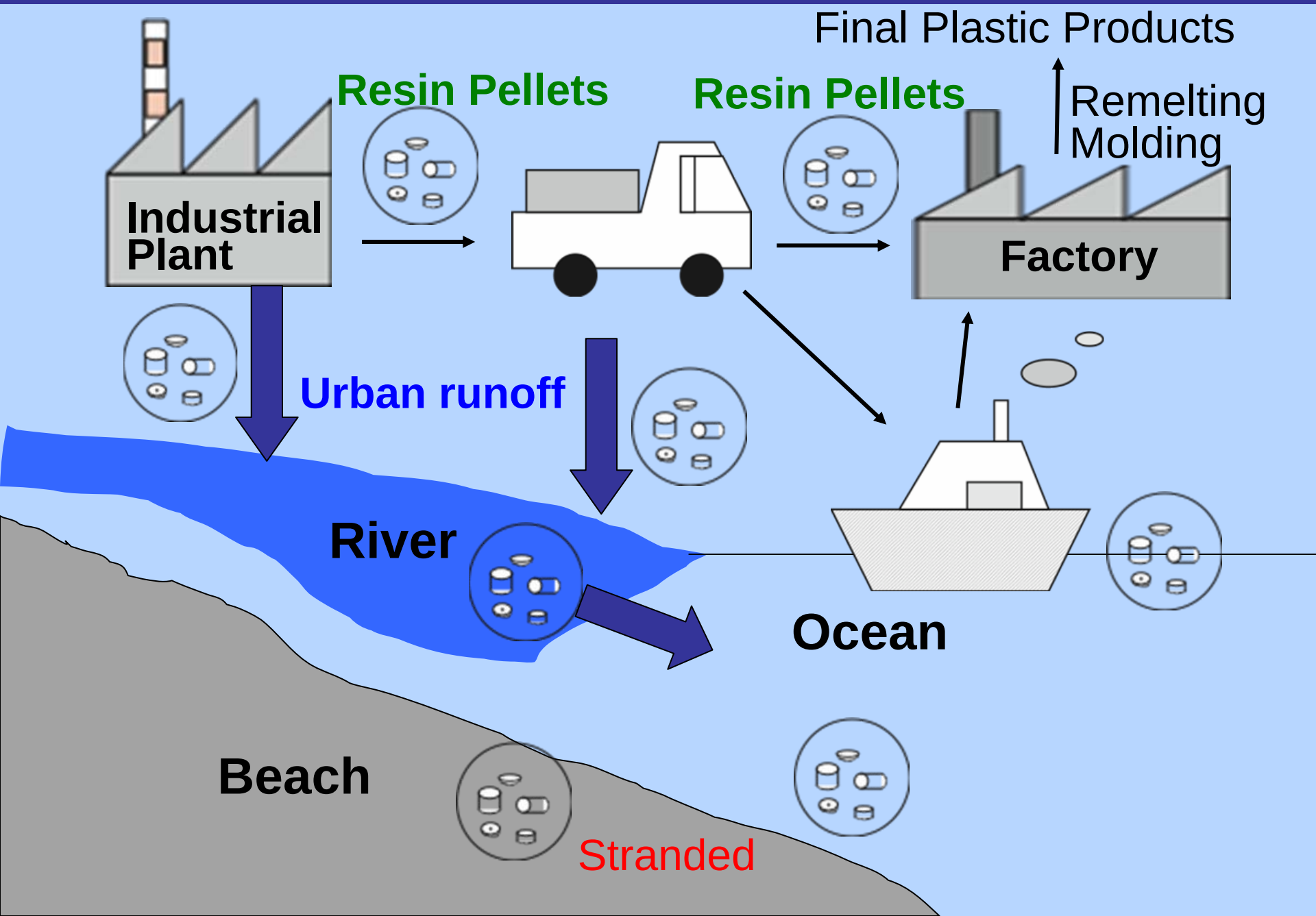
Laboratory of Organic Geochemistry (LOG), Tokyo University of Agriculture and Technology, Tokyo, Japan

Topics

- ✓ International Pellet Watch : Monitoring of POPs using beached plastic resin pellets.
- ✓ Organic micropollutants in plastic fragments : adsorption and additives.
- ✓ Potential transfer of organic micropollutants from marine plastics to seabirds.

Plastic Resin Pellets

Why Plastic Resin Pellets are found in the ocean?

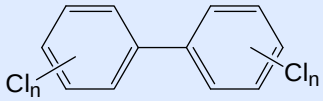


Plastic Resin Pellets as a Transport Medium for Toxic Chemicals in the Marine Environment

Environmental Science & Technology
2001, vol.35, 318-324

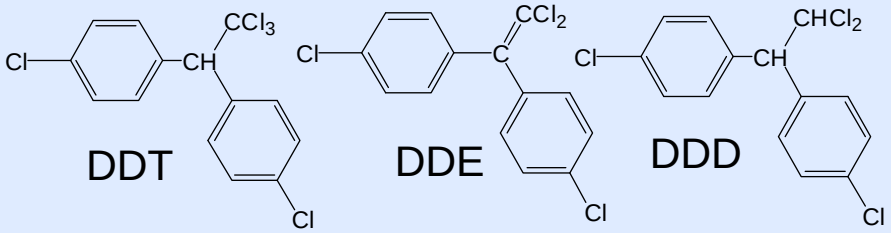
Pellets accumulate POPs from seawater

PCBs



- Industrial products for a variety of uses including dielectric fluid, heat medium, and lubricants.
- Endocrine disrupting chemicals

DDTs

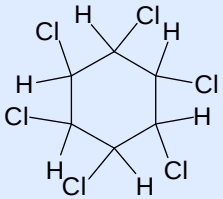


- DDT and its metabolites such as DDE and DDD.
- DDT was used as insecticides
- Endocrine disrupting chemicals

adsorption from ambient seawater

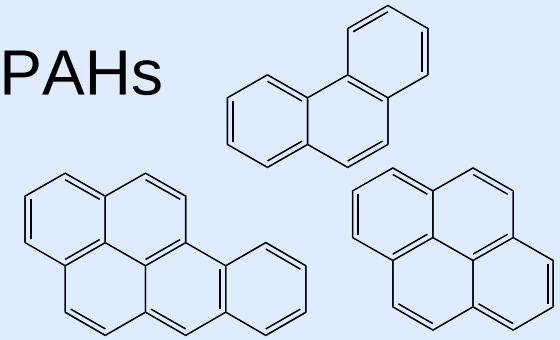
Pellet

HCH



- Insecticide

PAHs



International Pellet Watch

Global Monitoring of Persistent Organic Pollutants (POPs) Using Beached Plastic Resin Pellets

Since 2005

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Available online at www.sciencedirect.com
ScienceDirect

Marine Pollution Bulletin 52 (2006) 1547–1548

MARINE POLLUTION BULLETIN

www.elsevier.com/locate/marpolbul

Editorial

Call for pellets! International Pellet Watch Global Monitoring of POPs using beached plastic resin pellets

On our beaches, we see various quantities of many materials (e.g., seaweed, driftwood, trash, plastic fragments, cigarette ends) along the high-tide line. Among them, we can commonly find plastic resin pellets. Recently we have started a global monitoring programme of persistent organic pollutants (POPs) using these stranded plastic resin pellets (International Pellet Watch: http://www.tuat.ac.jp/~gaia/ipw/index.html).

Plastic resin pellets are small granules, generally with shape of a cylinder or a disk with a diameter of a few mm (Fig. 1). These plastic particles are the industrial raw material of plastics which are transported to manufacturing sites where "user plastics" are made by re-melting the pellets and molding them into the final products. Resin pellets can be unintentionally released to the environment, both during manufacturing and transport. The released resin pellets are carried by surface run-off, streams and river waters, eventually leading to the ocean. Because of their environmental persistence, they are distributed widely in the ocean and are now found on beaches all over the world. In 2001, we revealed the existence of various organic micro-pollutants (i.e., polychlorinated biphenyls: PCBs, DDE, and nonylphenol) in these stranded plastic resin pellets collected on beaches (Mato et al., 2001).

Fig. 1. Plastic resin pellets.

Because of the hydrophobic nature of the plastic surfaces, hydrophobic pollutants such as PCBs and DDTs are adsorbed to the pellets from the surrounding seawater with concentration factors of up to 10^6. We observed a weak correlation between PCBs concentrations in plastic resin pellets collected on beaches with levels in traditional monitoring media (i.e., mussels), although large piece-to-piece variability of PCB concentrations was also observed (Endo et al., 2005). Because the resin pellets are distributed on beaches the world over, and because collection and shipping of the pellets are easy, we propose global monitoring of persistent organic pollutants (POPs) using these beached plastic resin pellets.

In the International Pellet Watch project, we ask people from all countries to collect plastic resin pellets on their nearby beaches and send them to our laboratory via airmail. No cooling nor freezing is necessary during shipment. People just need to put the pellets into a paper envelope and post it to us. To get representative data, we need 100–200 pieces of pellets (preferably yellowed pellets) from each location. Organic micro-pollutants in the pellets will be analyzed in our laboratory. Based on the analytical results, global distributions of these organic micro-pollutants will be mapped. Results will be sent to the participants through e-mail and will be released on the web as well.

The purpose of International Pellet Watch is to understand the current status of global POPs pollution, and the advantage of Pellet Watch is its extremely low cost of sampling and shipping as compared with conventional monitoring using water, sediment and biological samples. Further, we can draw global POPs pollution maps for a very low cost. Already several NGOs who conduct beach clean-up projects are helping with sample collection.

So far, our spatial coverage is very limited and of course the strength of the programme will be related to the coverage

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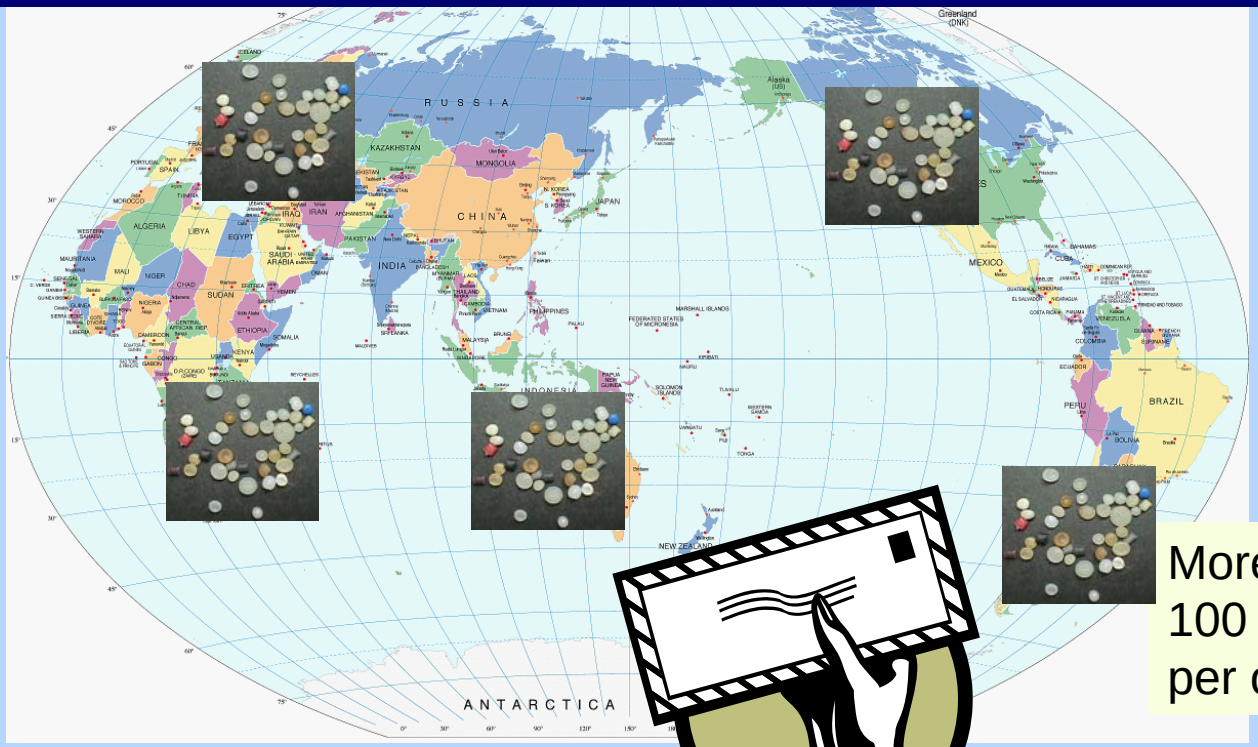
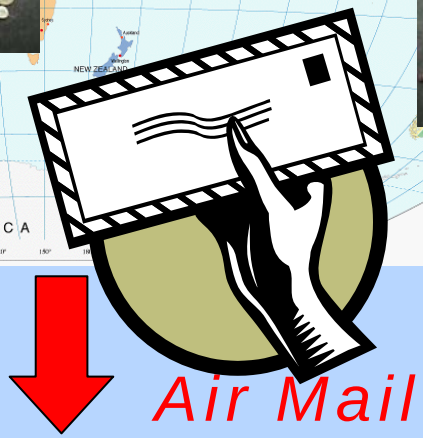
International Pellet Watch

Global Monitoring of Persistent Organic Pollutants (POPs) Using Beached Plastic Resin Pellets



More than 50 pieces (~ 100 pieces) per one location



Laboratory of Organic Geochemistry, Dr. Hideshige Takada,
Tokyo University of Agriculture and Technology,
Fuchu, Tokyo 183-8509, Japan

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Dr. Hideshige Takada,
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More than 50 pieces (~100 pieces) per one location

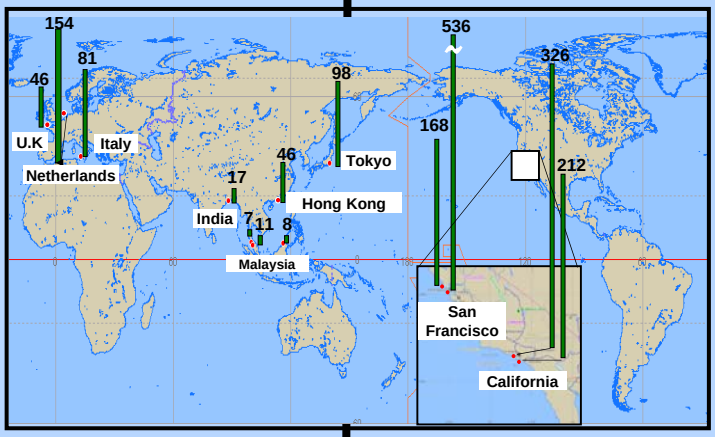
Sorting

PE, yellowing pellets

Analysis for POPs (PCBs, organochlorines, PAHs)

By GC-MS/MS, GC-MS, GC-ECD
more than 5 pools of 5 pellets
to exclude sporadic high concentration

Mapping POPs pollution



- **Sending the data** via Internet to the collaborators
- **Releasing** the results on **web**

Advantage of Pellet Watch

Extremely low cost for sampling and shipping

No special training is necessary for sampling

↓

World citizens can join

↓

Wide area (globe) can be monitored using minimal cost

Activities to call for pellets

Available online at www.sciencedirect.com
ScienceDirect
Marine Pollution Bulletin 52 (2006) 1547–1548
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

Editorial

Call for pellets! International Pellet Watch Global Monitoring of POPs using beached plastic resin pellets

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Fig. 1. Plastic resin pellets.

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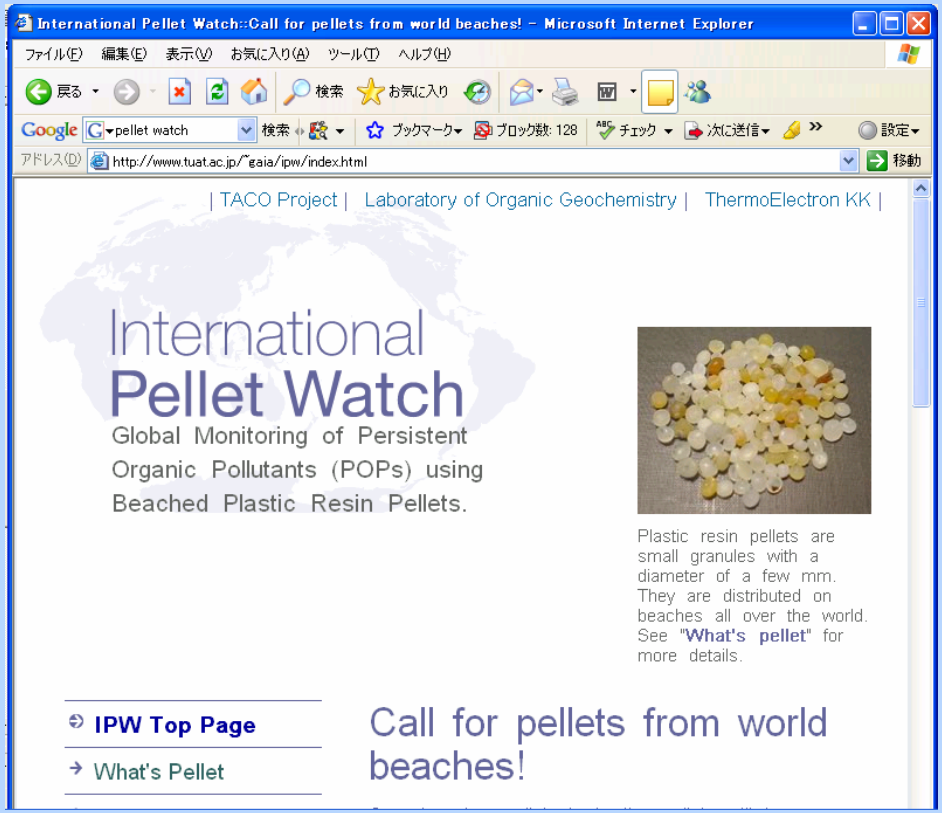
Articles on International journals

Presentation on international conferences



Homepage on web

http://www.tuat.ac.jp/~gaia/ipw/index.html

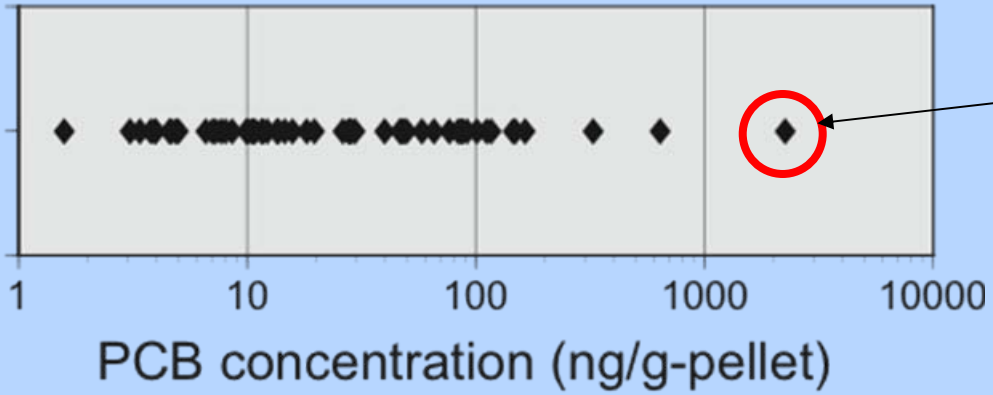
Beached pellets from 30 locations of 17 countries

Sorting and analysis of beached resin pellets for monitoring of PCBs

Sorting

Polyethylene (PE)

Yellowing



(Endo et al., 2005)

To exclude sporadic high concentrations of PCBs

Multiple 10-pellet pools are analyzed for PCBs

Median concentrations

Analytical Method

Plastic Resin Pellets

Sorting

near-infrared spectroscopy
(PlaScan-SH)

Yellowing PE pellets

Maceration Extraction

n-Hexane

Fully activated silica gel column chromatography
(0.46 cm i.d. x 18cm)

Hexane

6 ml

Alkanes
Hopanes

GC-MS

25 ml

PCBs, DDE

GC-MS/MS

25% DCM in Hexane

8 ml

PAHs
DDT, DDD
HCHs

GC-MS, GC-ECD

m/z=203
m/z=133
m/z=91
Samurai GC-MS
5890

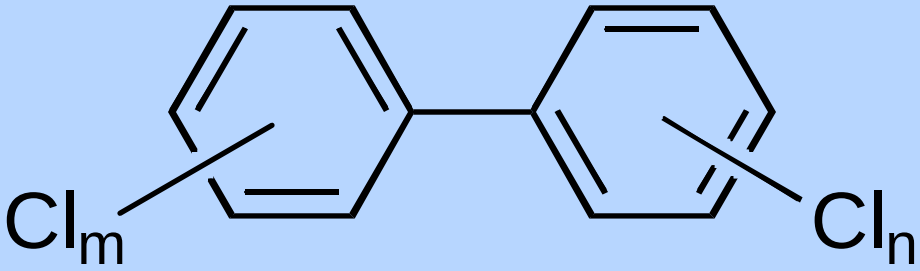
Samurai Mass-spec. 2006

Scientific collaboration with

Thermo
ELECTRON CORPORATION

Polaris *Q* GC-MS/MS

Polychlorinated biphenyls (PCBs)

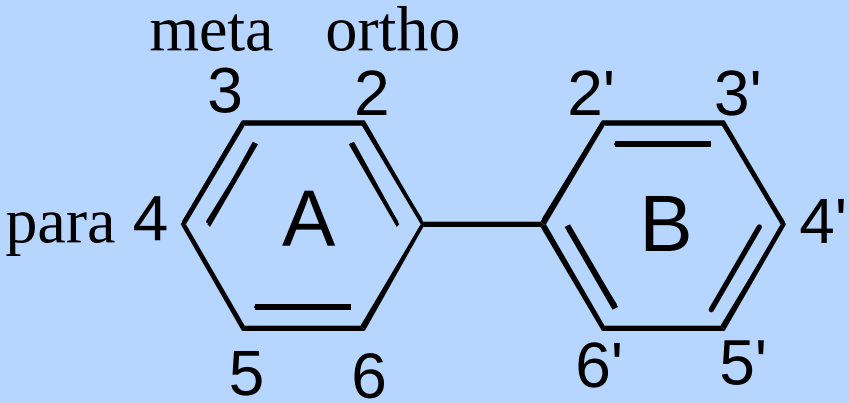


m + n = 1 - 10

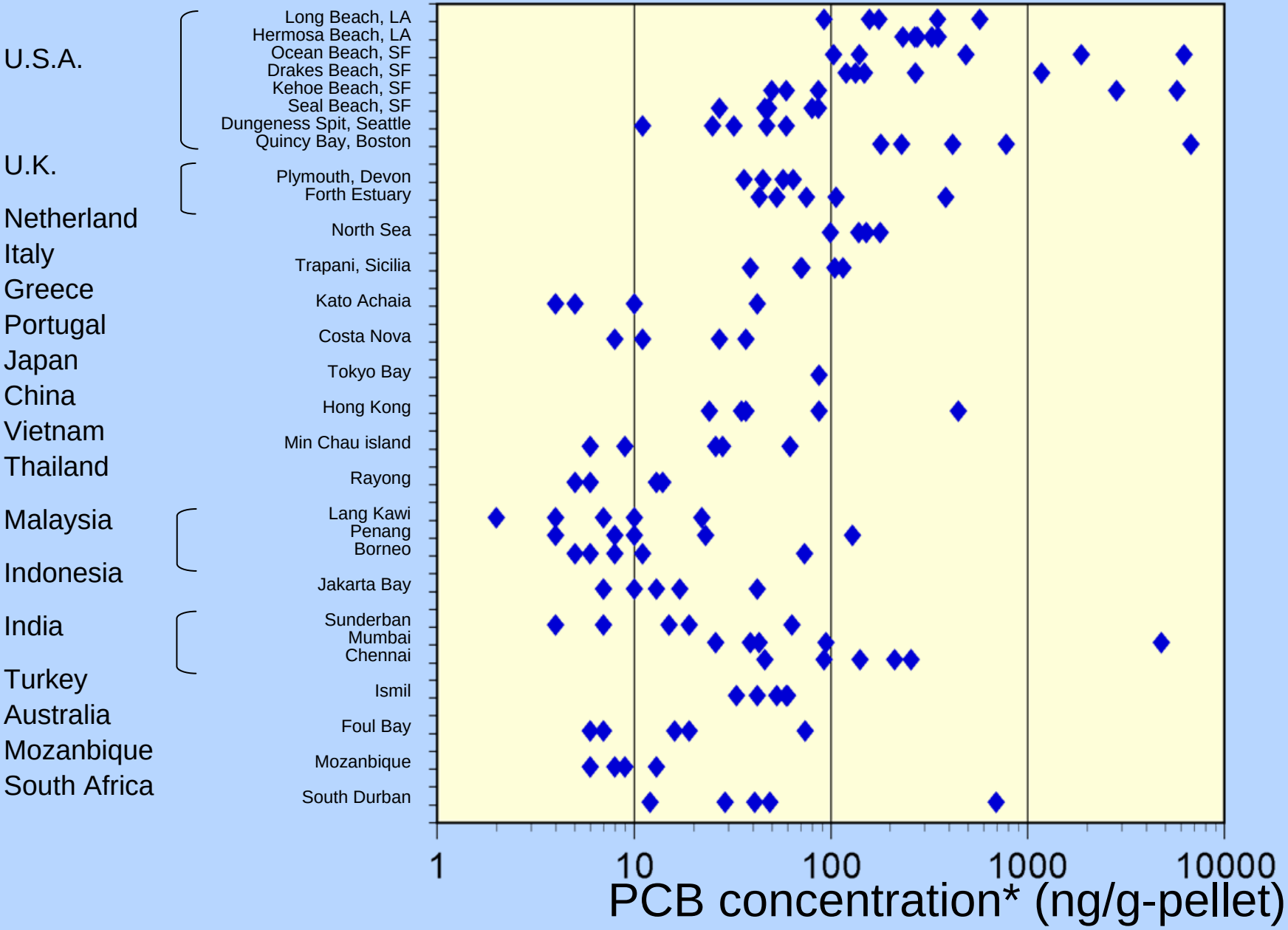
Congener

Homologs

Isomers

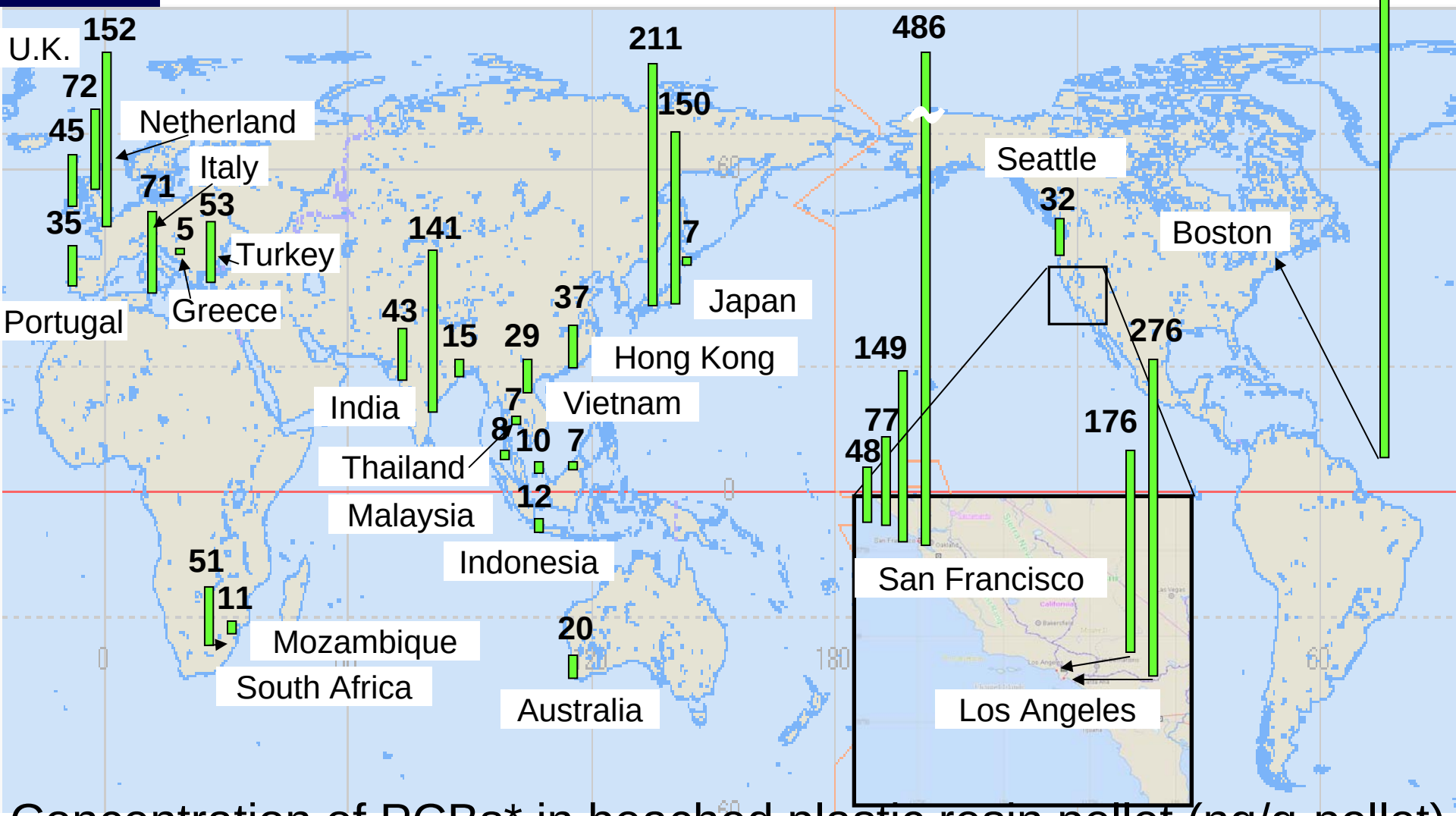


Analytical Results on PCBs in beached pellets



PCB concentration : sum of concentrations of CB# 66, 101, 110, 149, 118, 105, 153, 138, 128, 187, 180, 170, 206.

PCBs



Concentration of PCBs* in beached plastic resin pellet (ng/g-pellet)

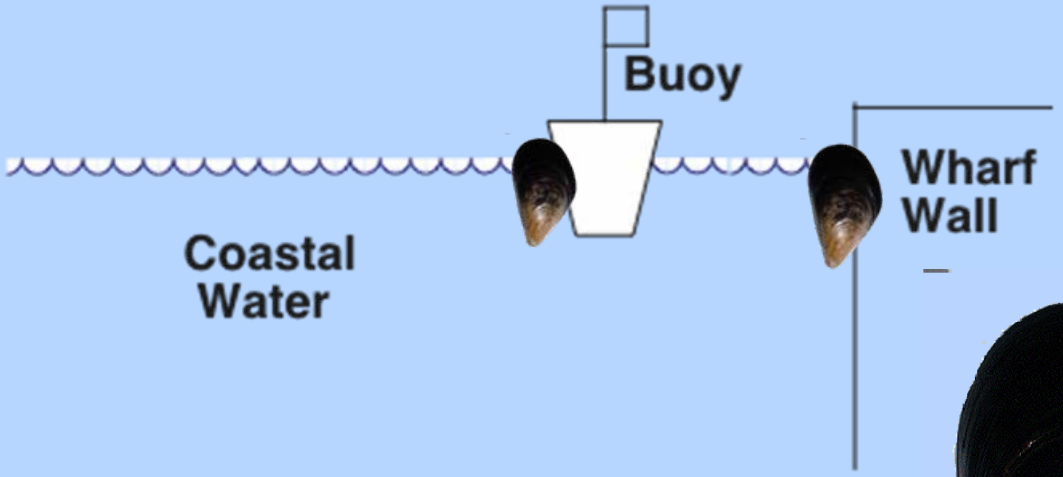
*sum of concentrations of CB#66, 101, 110, 149, 118, 105, 153, 138, 128, 187, 180, 170, 206

Measured by Polaris Q (Thermo Fisher Scientific)

Mussel Watch?

Mussel Watch

Monitoring methodology of coastal pollution using bivalves as sentinel organism



Organic micropollutants

e.g. Hydrocarbons
PCBs
Pesticides

Uptake

→

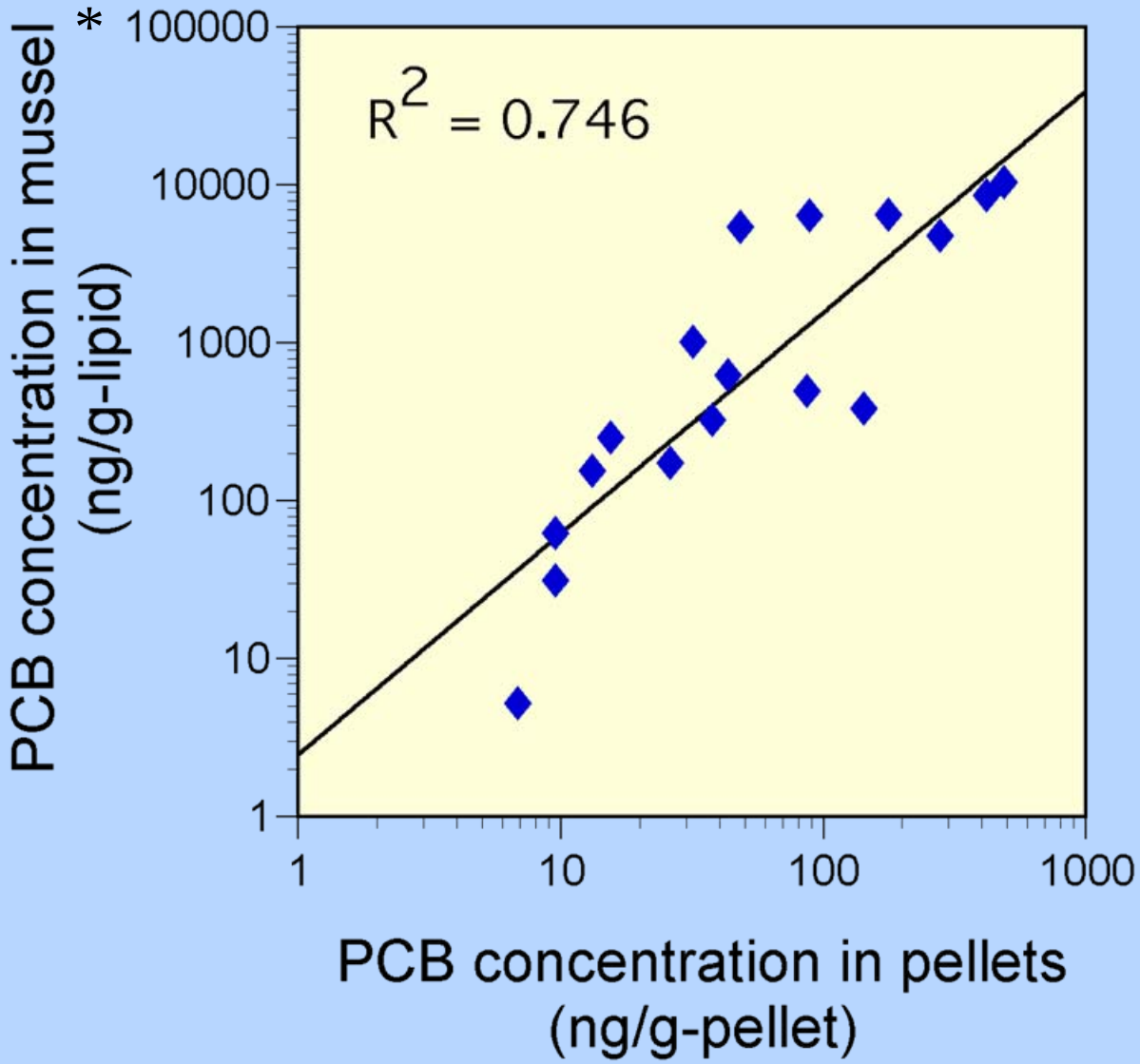
Accumulation

Heavy Metals

MUSSEL

(*Mytilus galloprovincialis*)

Correlation of PCB concentrations between beached pellets and mussels



*Data on mussels : after Yamaguchi et al. 2000, Monirith et al. 2003, NOAA 2007)

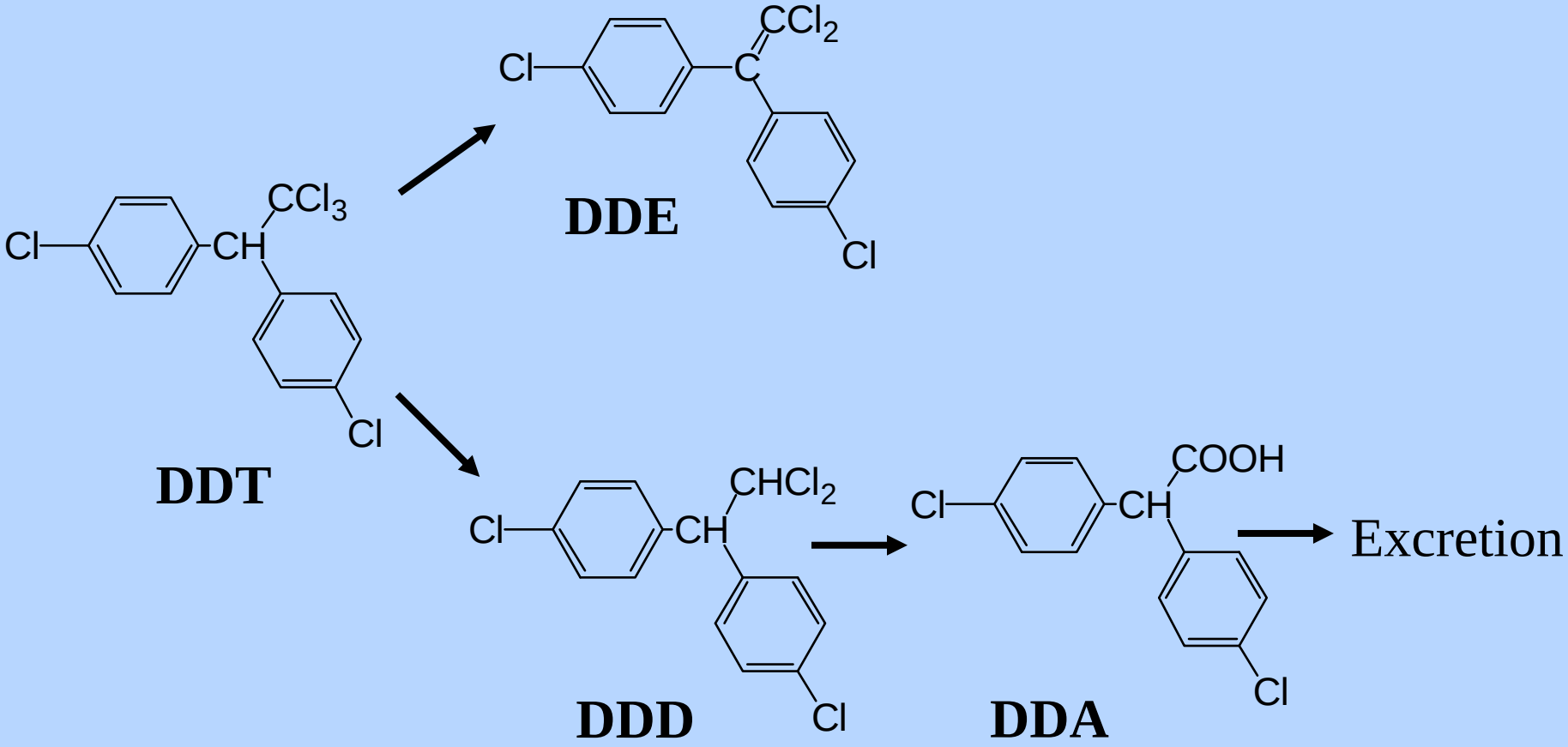
DDT and its metabolites

DDT (**D**ichloro-**d**iphenyl-**t**richloroethane) Insecticide

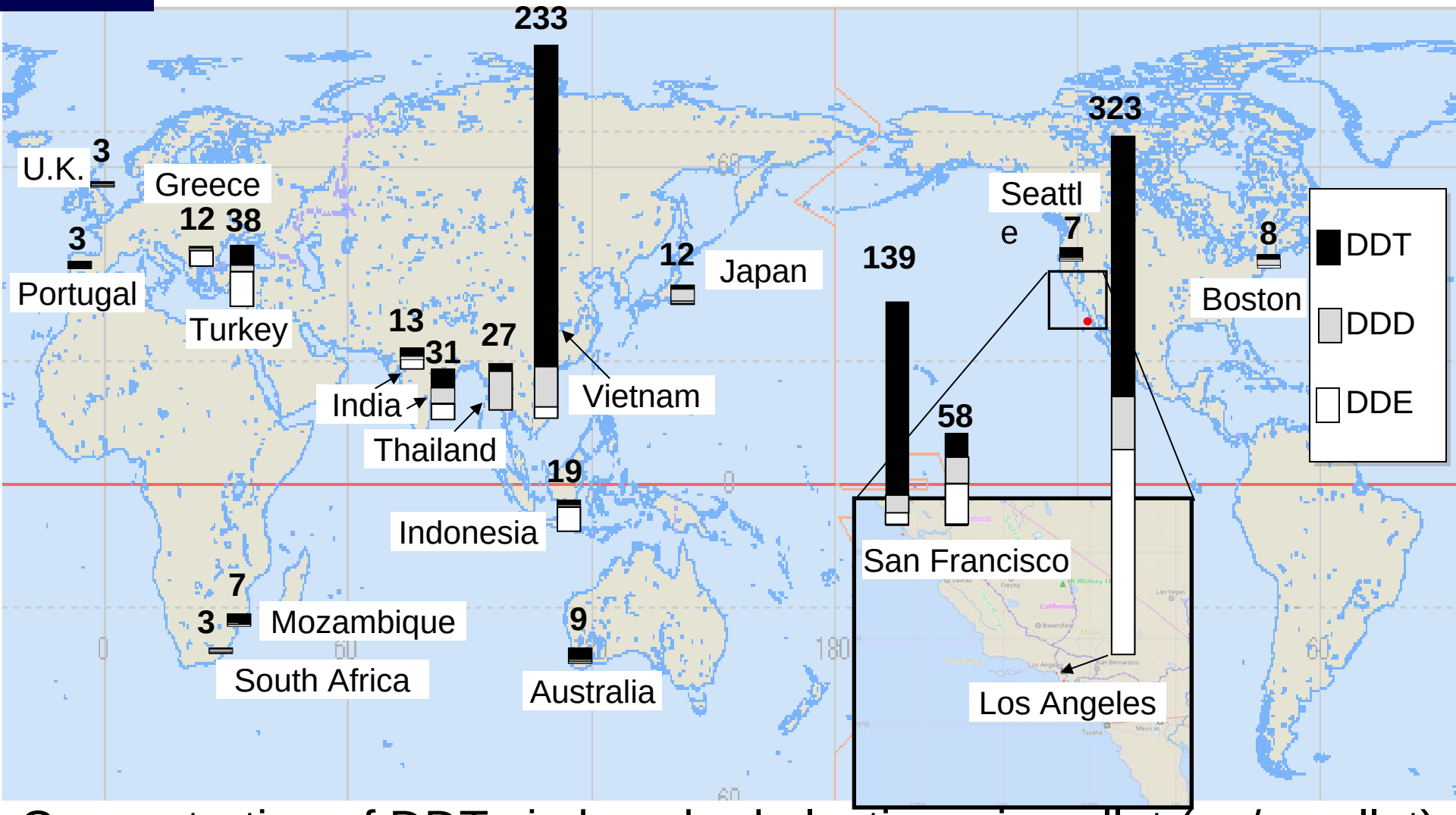
DDE (**D**ichloro-**d**iphenyl-dichloro**e**thylene)

DDD (**D**ichloro-**d**iphenyl-**d**ichloroethane)

DDA (**D**icloro-**d**iphenyl-**a**cetic acid)



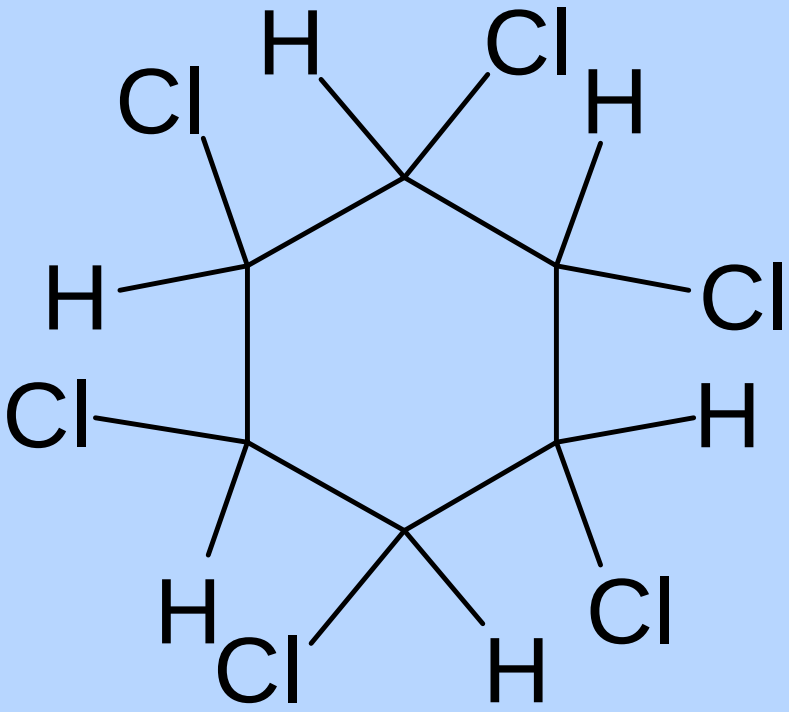
DDTs



Concentration of DDTs in beached plastic resin pellet (ng/g-pellet)

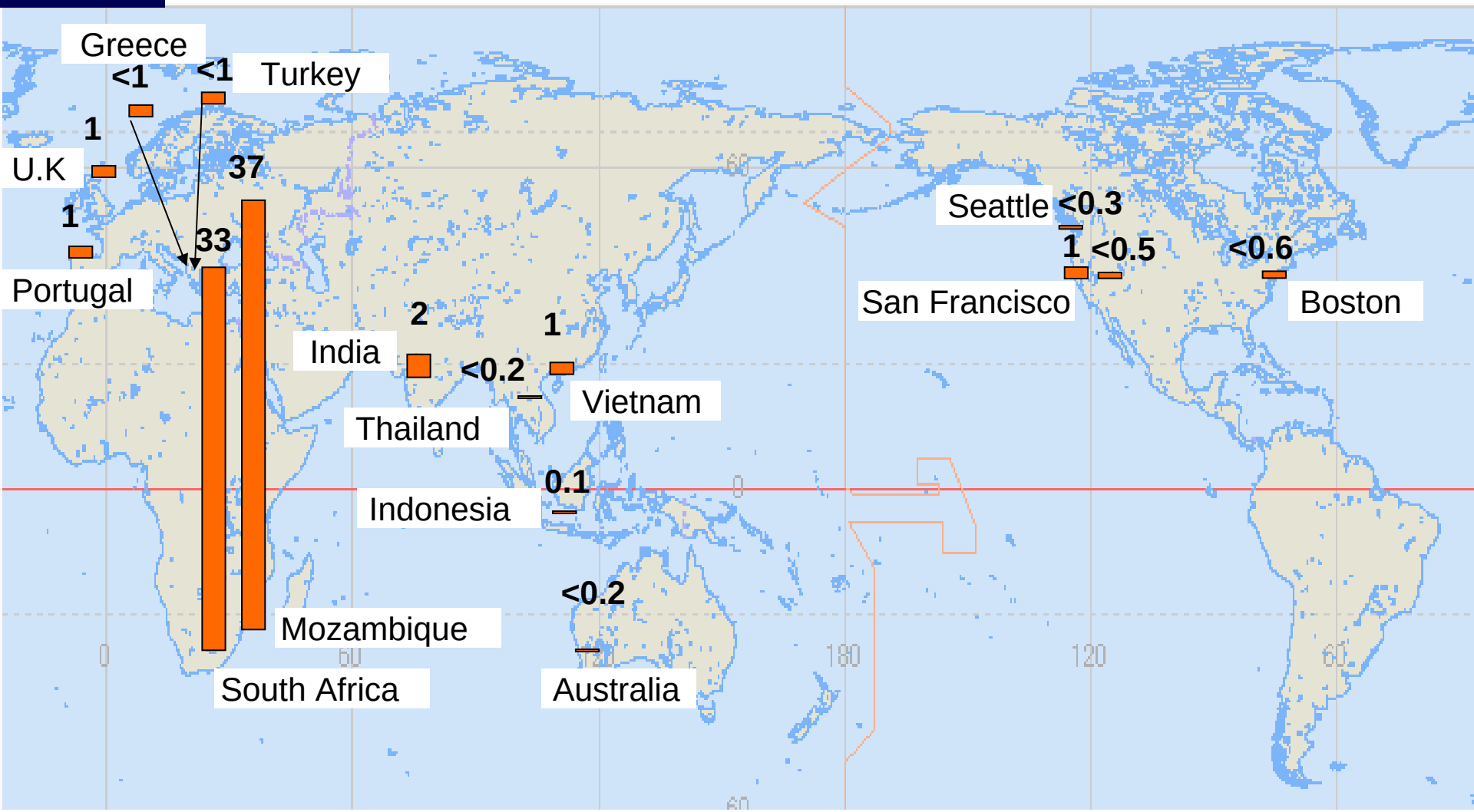
HCHs

Hexachloro-cyclohexanes



Insecticide

HCHs



Concentration of HCHs* in beached plastic resin pellet (ng/g-pellet)

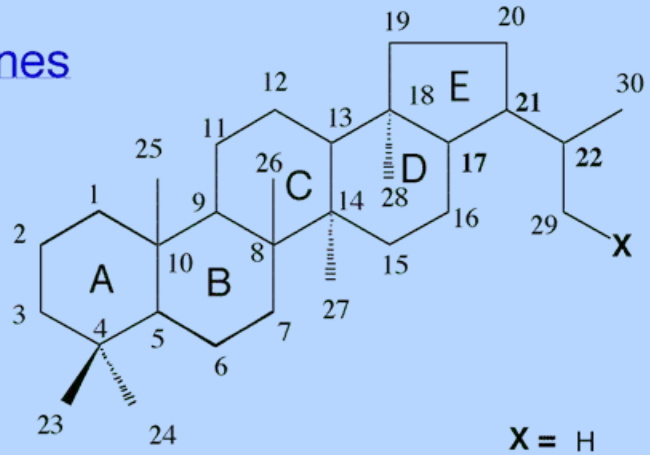
*sum of α, β, χ. δ isomers

Hopanes : Molecular markers of petroleum pollutions

Hopanes : Molecular Markers of Petroleum Pollution

- ubiquitous in crude oils
- numerous homologes and stereo isomers which are specific to sources of the oils
- persistent to environmental alteration

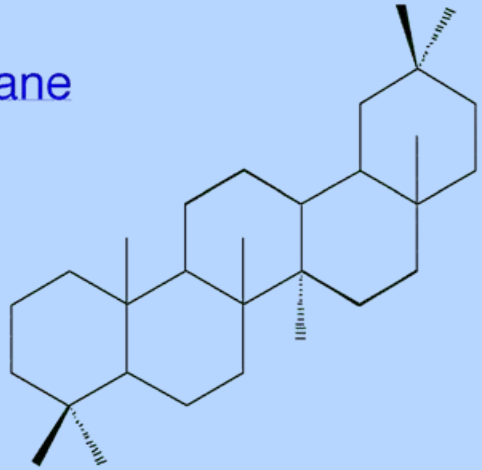
Hopanes



		Trisnorhopane	C_{27}
		Norhopane	C_{29}
X =	H	**Hopane**	C_{30}
	CH_3	Homohopane	C_{31}
	C_2H_5	Bishomohopane	C_{32}
	C_3H_7	Trishomohopane	C_{33}
	C_4H_9	Tetrakishomohopane	C_{34}
	C_5H_{11}	Pentakishomohopane	C_{35}

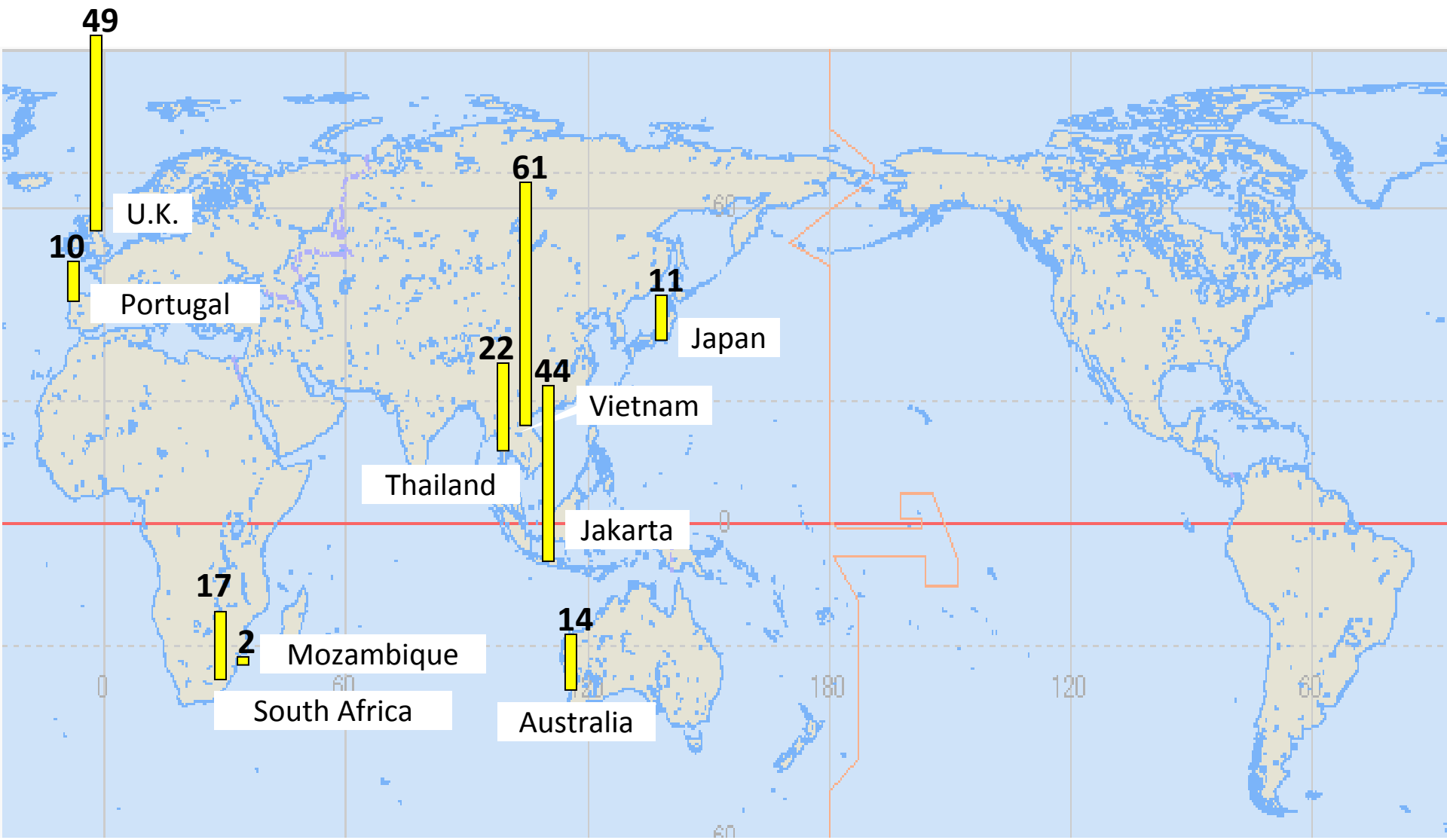
Derived from **bacterial cell wall**

Oleanane

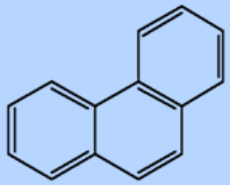


Derived from **higher plants**

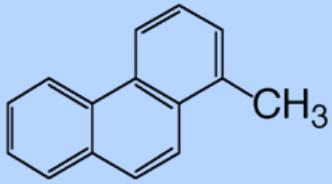
Hopane concentration in beached plastic pellet (ng/g-Pellet)



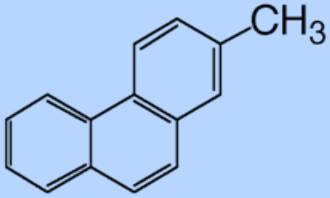
Polycyclic Aromatic Hydrocarbons (PAHs)



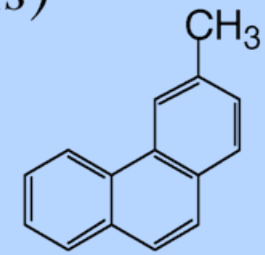
Phenanthrene



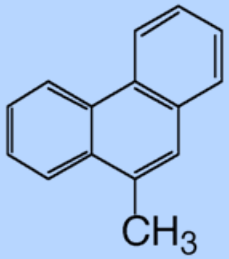
1-Methylphenanthrene



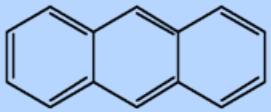
2-Methylphenanthrene



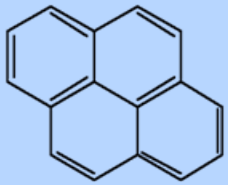
3-Methylphenanthrene



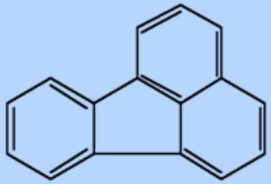
9-Methylphenanthrene



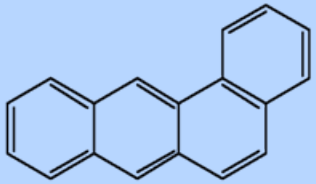
Anthracene



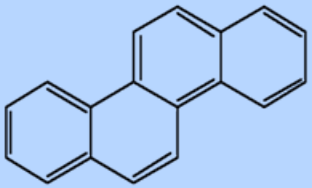
Pyrene



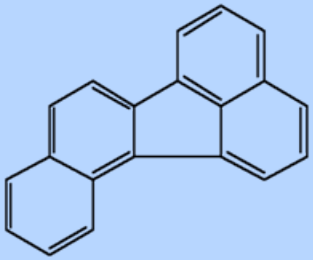
Fluoranthene



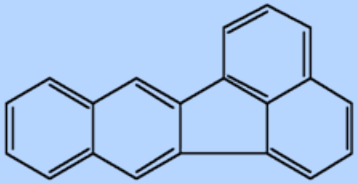
Benz[a]anthracene



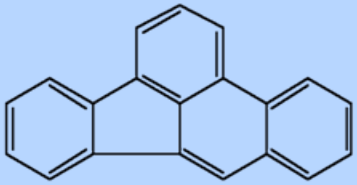
Chrysene



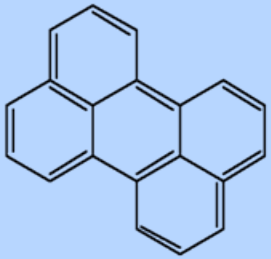
Benzo[j]fluoranthene



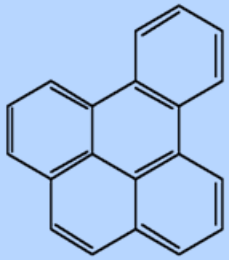
Benzo[k]fluoranthene



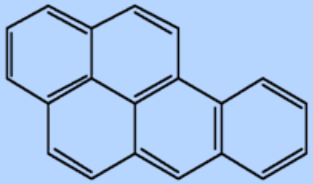
Benzo[b]fluoranthene



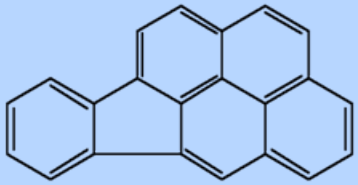
Perylene



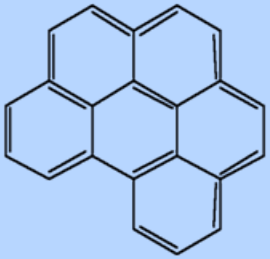
Benzo[e]pyrene



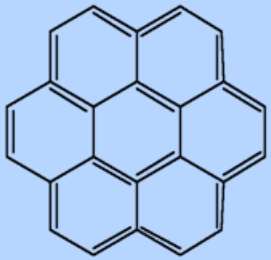
Benzo[a]pyrene



Indeno[1,2,3-cd]pyrene

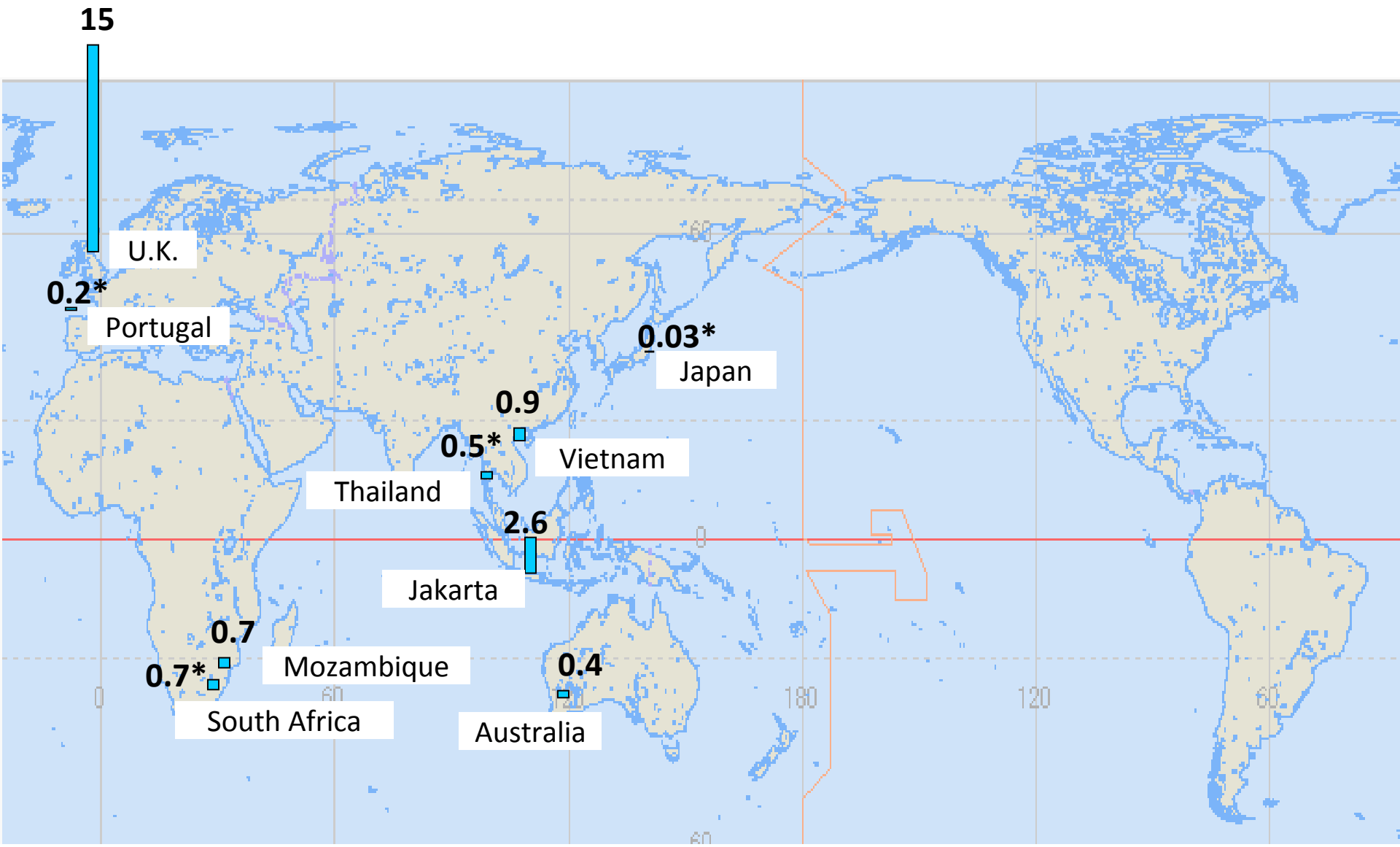


Benzo[ghi]perylene



Coronene

PAHs concentration in beached plastic pellet (ng/g-pellet)



*<LOQ

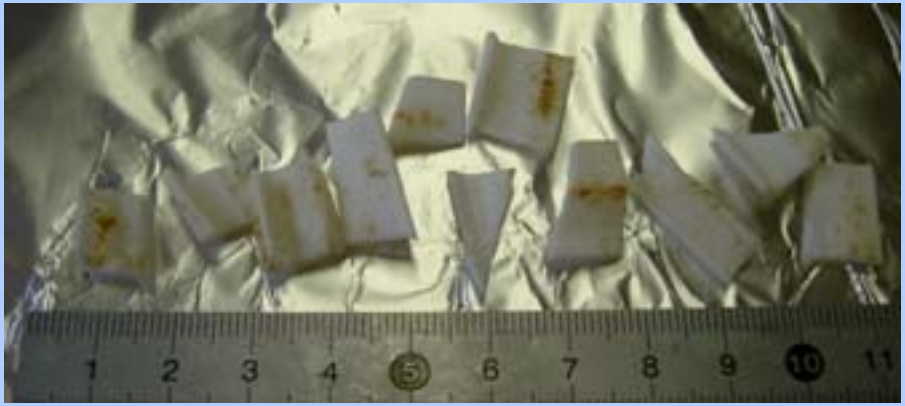
Conclusions of IPW

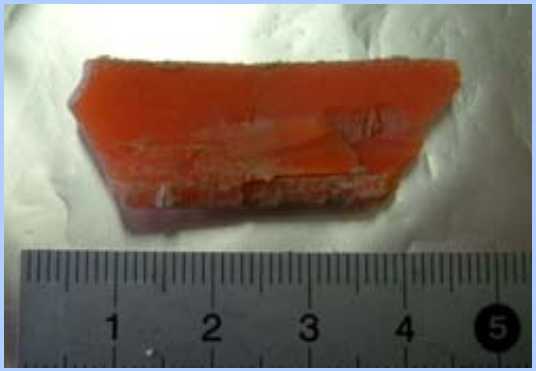
Global pollution maps of PCBs, organochlorine pesticides, and hydrocarbons were made based on the analysis of resin pellets from 30 beaches of 17 countries.

PCB and DDE concentrations in the beached pellets showed good correlation with those in conventional monitoring media (i.e., mussel).

Our analysis demonstrated the feasibility and usefulness of international pellet watch as a tool of global monitoring of POPs. Especially, pellet watch is useful in areas where conventional monitoring data are not available such as Africa.

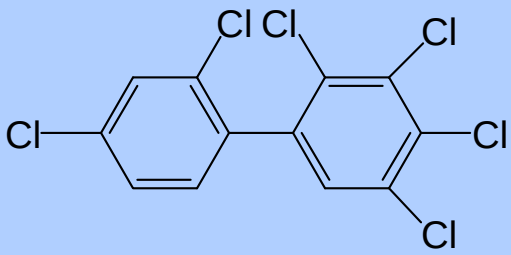
2. Organic micropollutants, especially additives, in plastic fragments in the ocean.



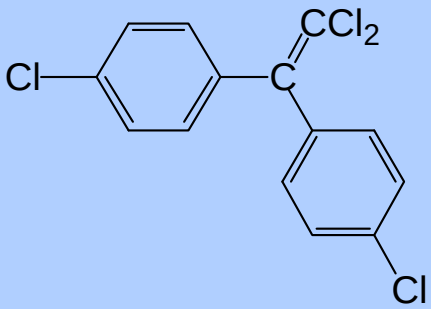


Contaminants found in marine plastic fragments

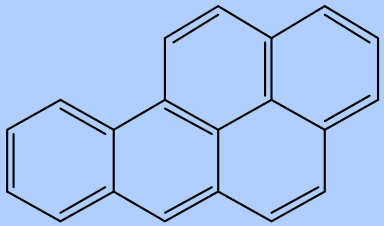
Sorption from ambient seawater



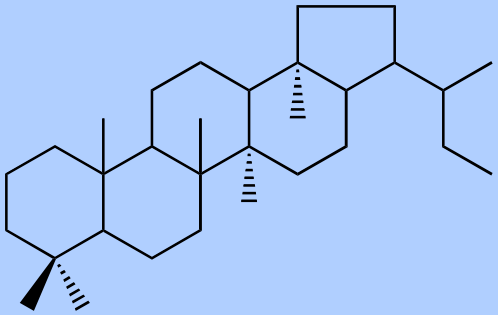
Polychlorinated biphenyl (PCBs)



DDTs

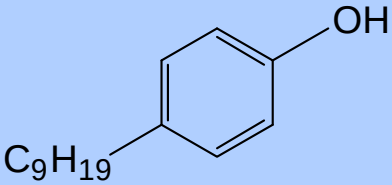


Polycyclic aromatic hydrocarbons (PAHs)

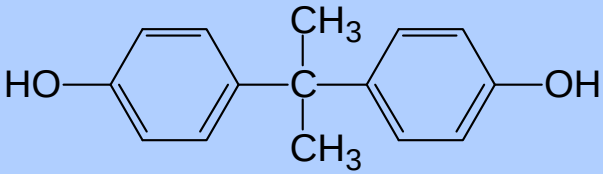


Petroleum Hydrocarbons

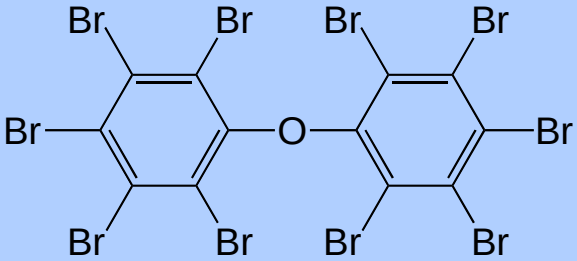
Additive-derived chemicals



Nonylphenol

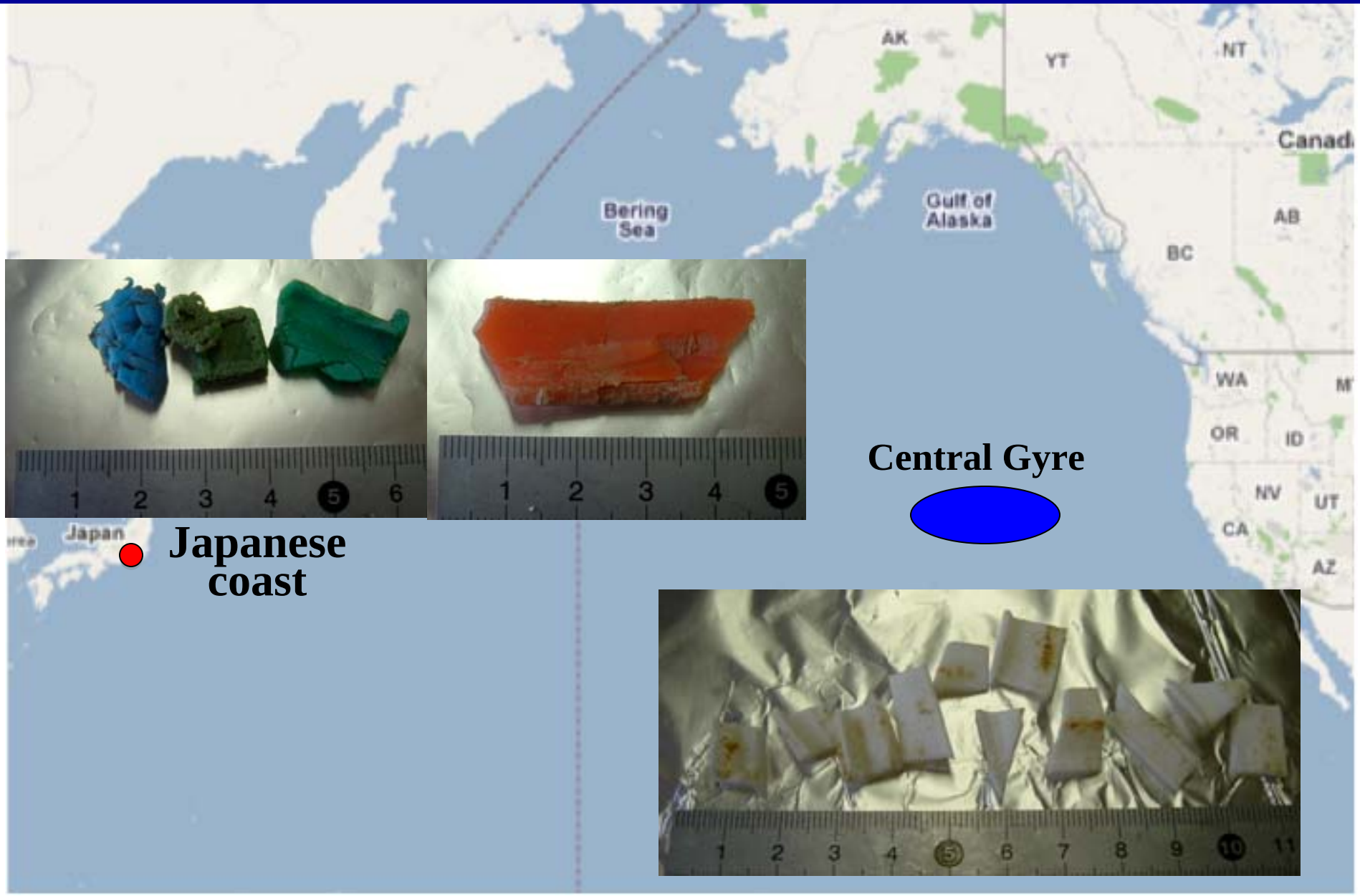


Bisphenol A

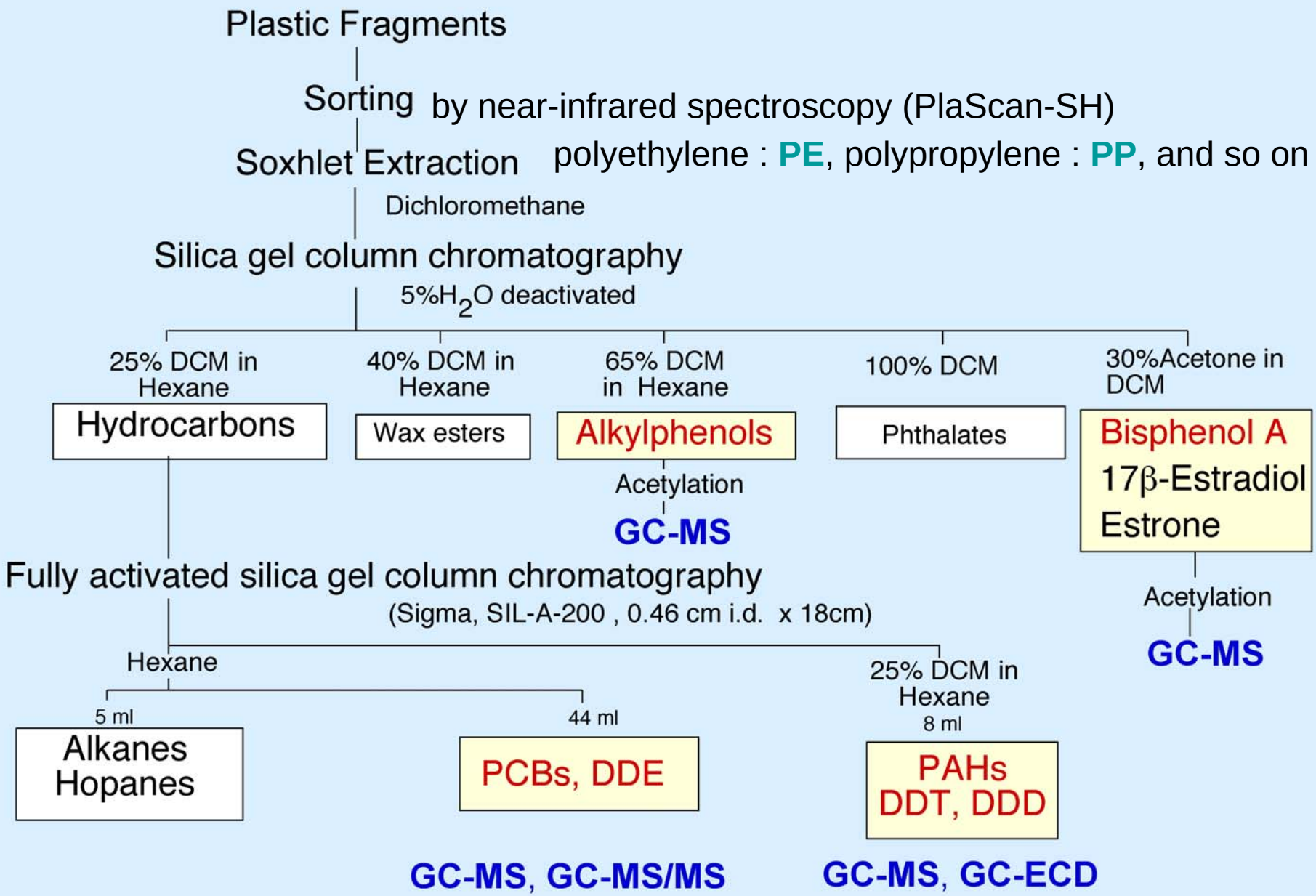


Polybrominated diphenyl ethers (PBDEs)

Sampling locations of plastic fragments



Analytical procedure of contaminants in plastic fragments



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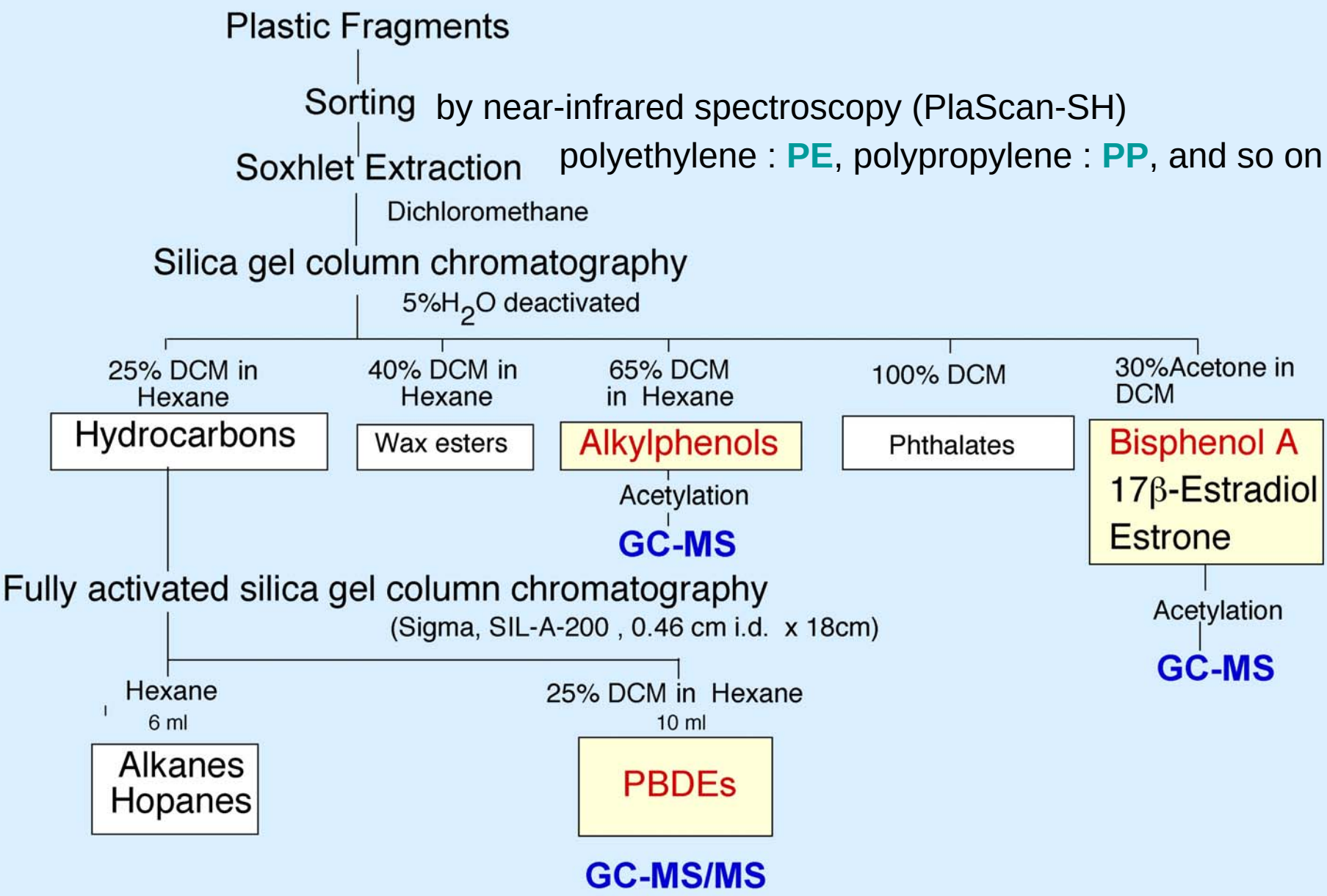

Contaminants found in marine plastic fragments

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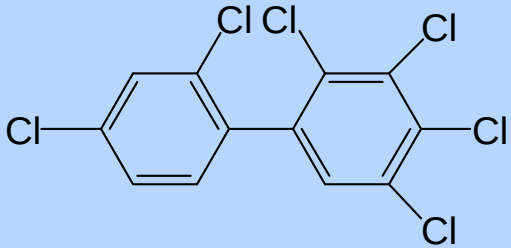

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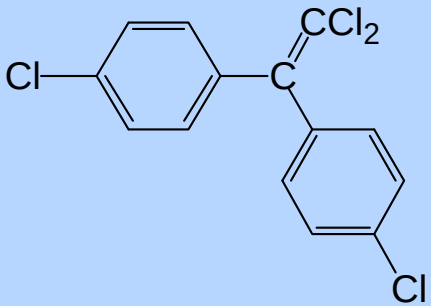
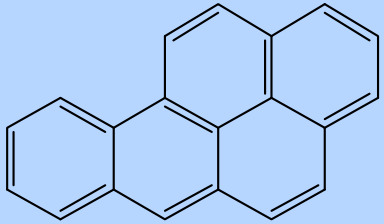


DDTs



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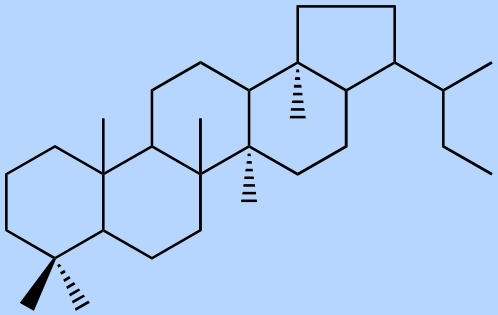
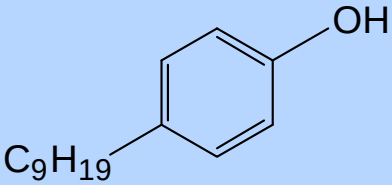
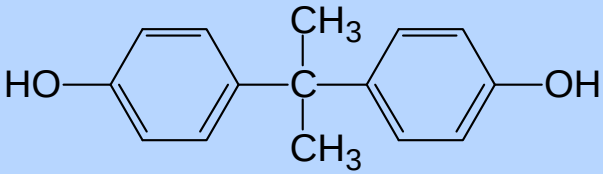


Petroleum Hydrocarbons

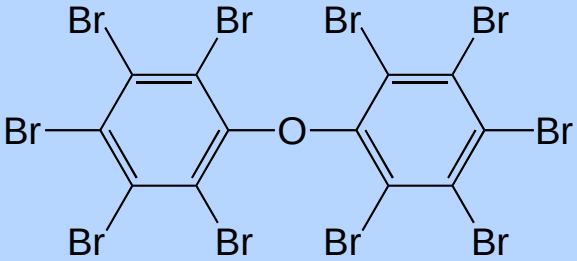
Additive-derived chemicals



Nonylphenol

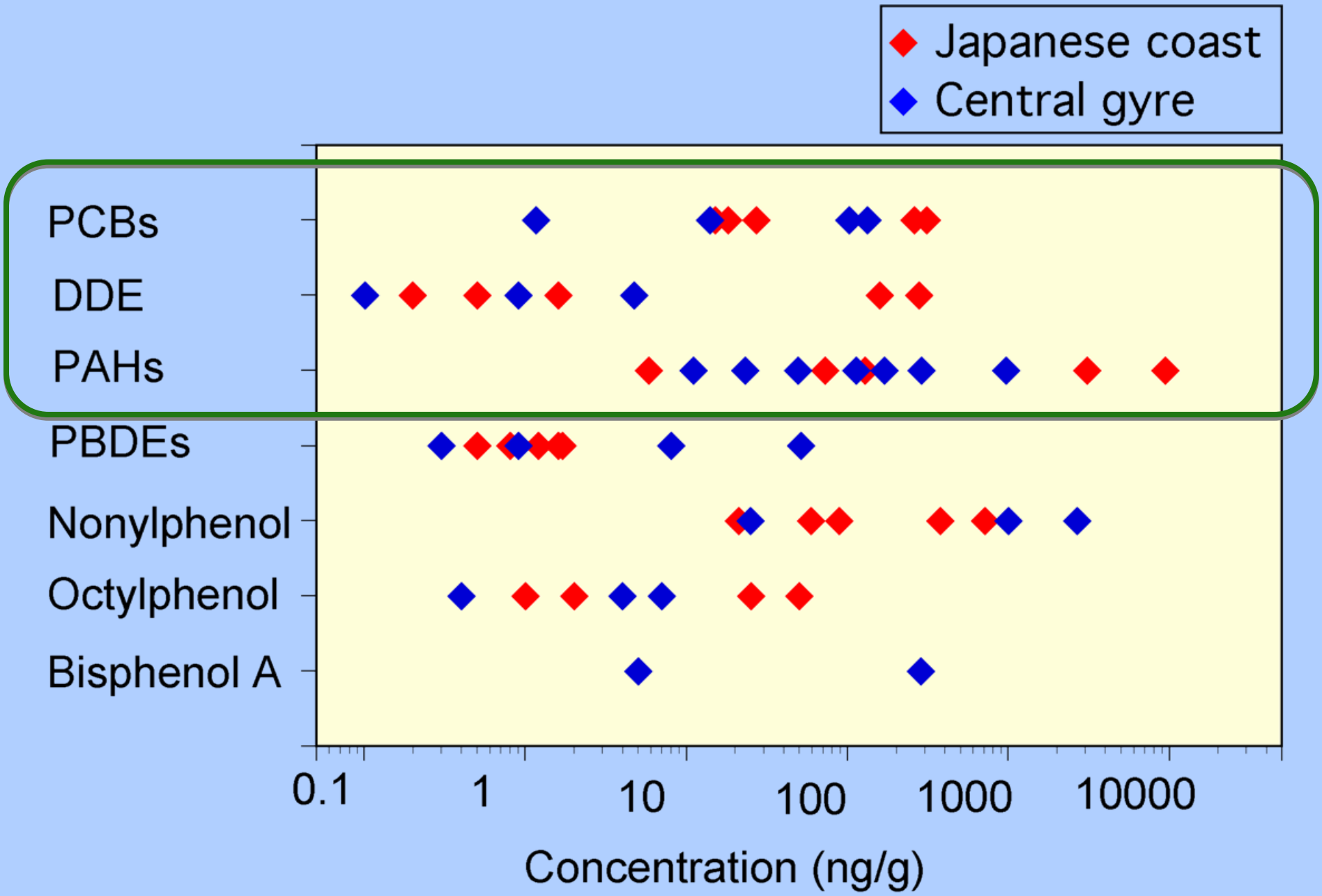


Bisphenol A

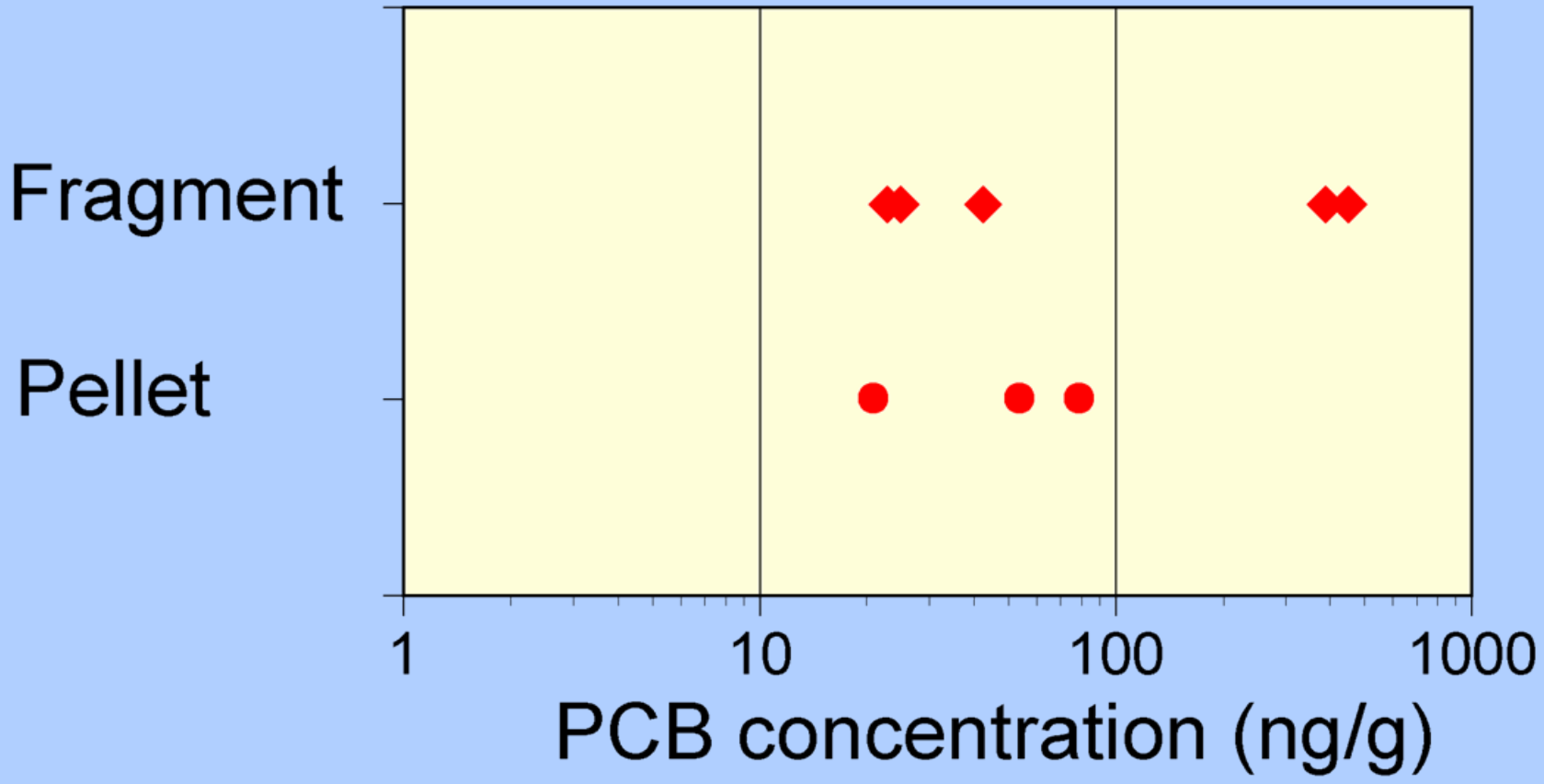


Polybrominated diphenyl ethers (PBDEs)

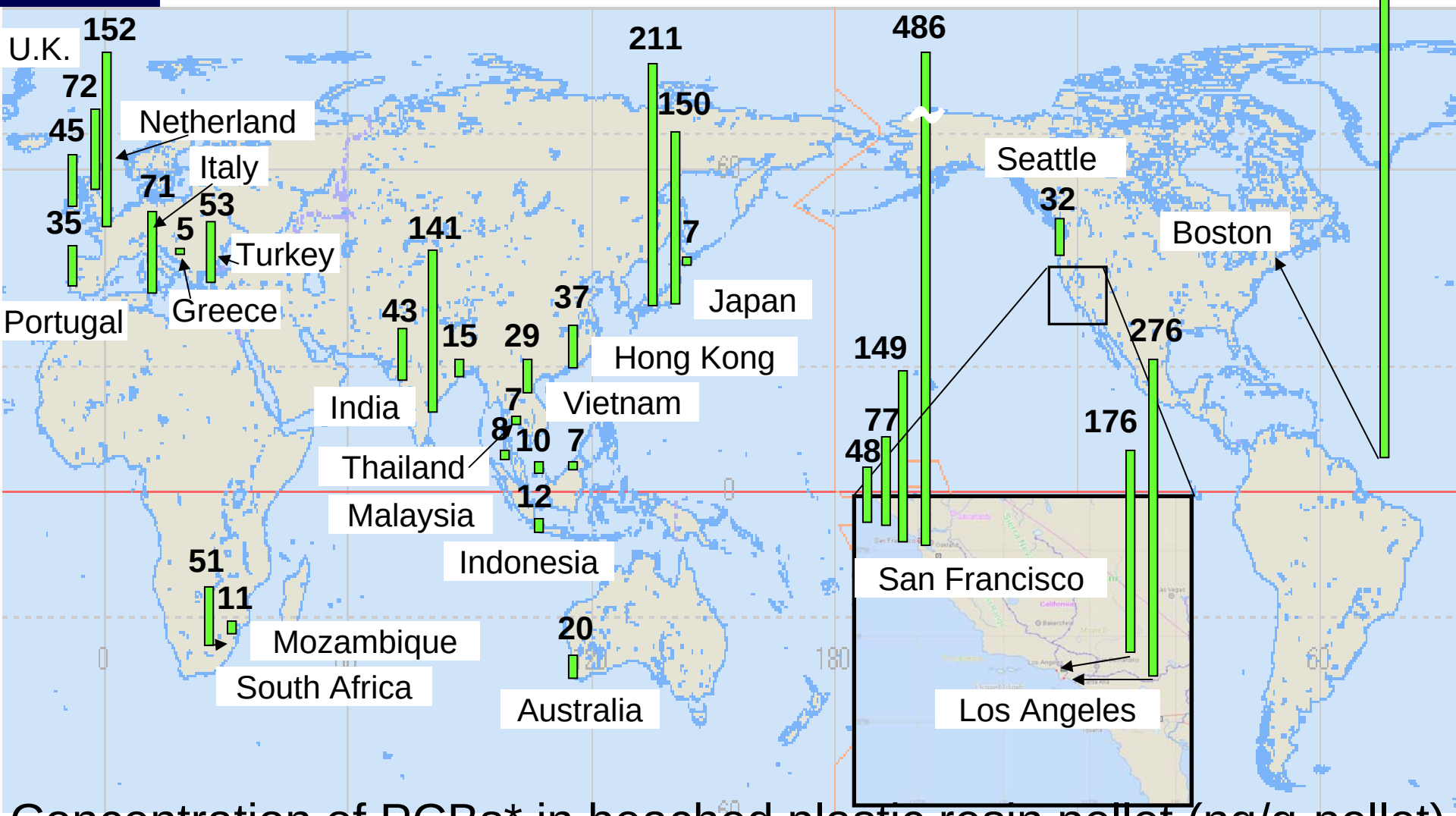
Broad-spectrum of contaminants in marine plastic fragments



Concentration range of PCBs in plastic fragments and pellets collected from a beach



PCBs



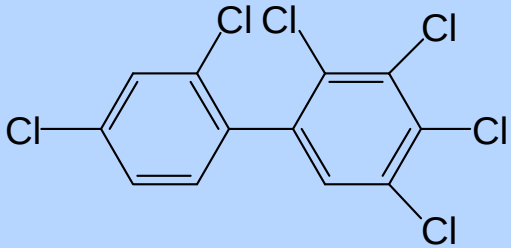
Concentration of PCBs* in beached plastic resin pellet (ng/g-pellet)

*sum of concentrations of CB#66, 101, 110, 149, 118, 105, 153, 138, 128, 187, 180, 170, 206

Measured by Polaris Q (Thermo Fisher Scientific)

Contaminants found in marine plastic fragments

Sorption from ambient seawater



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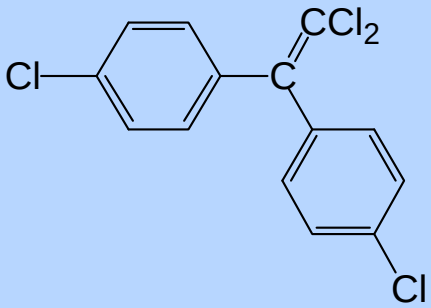
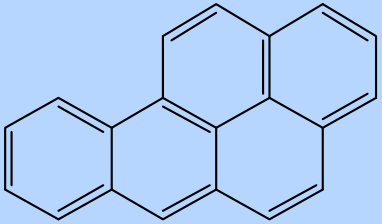


DDTs



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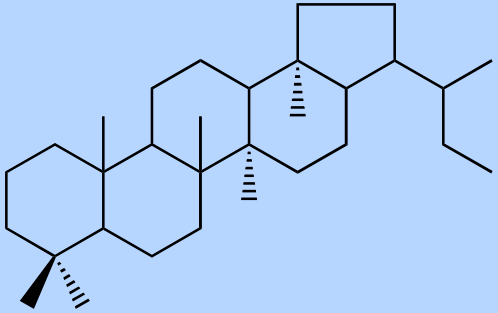
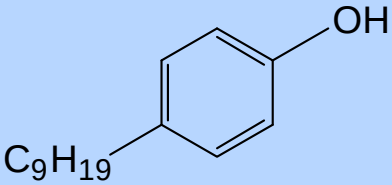
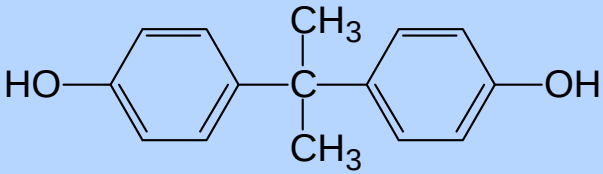


Petroleum Hydrocarbons

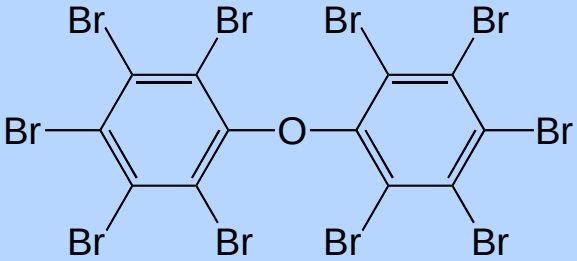
Additive-derived chemicals



Nonylphenol

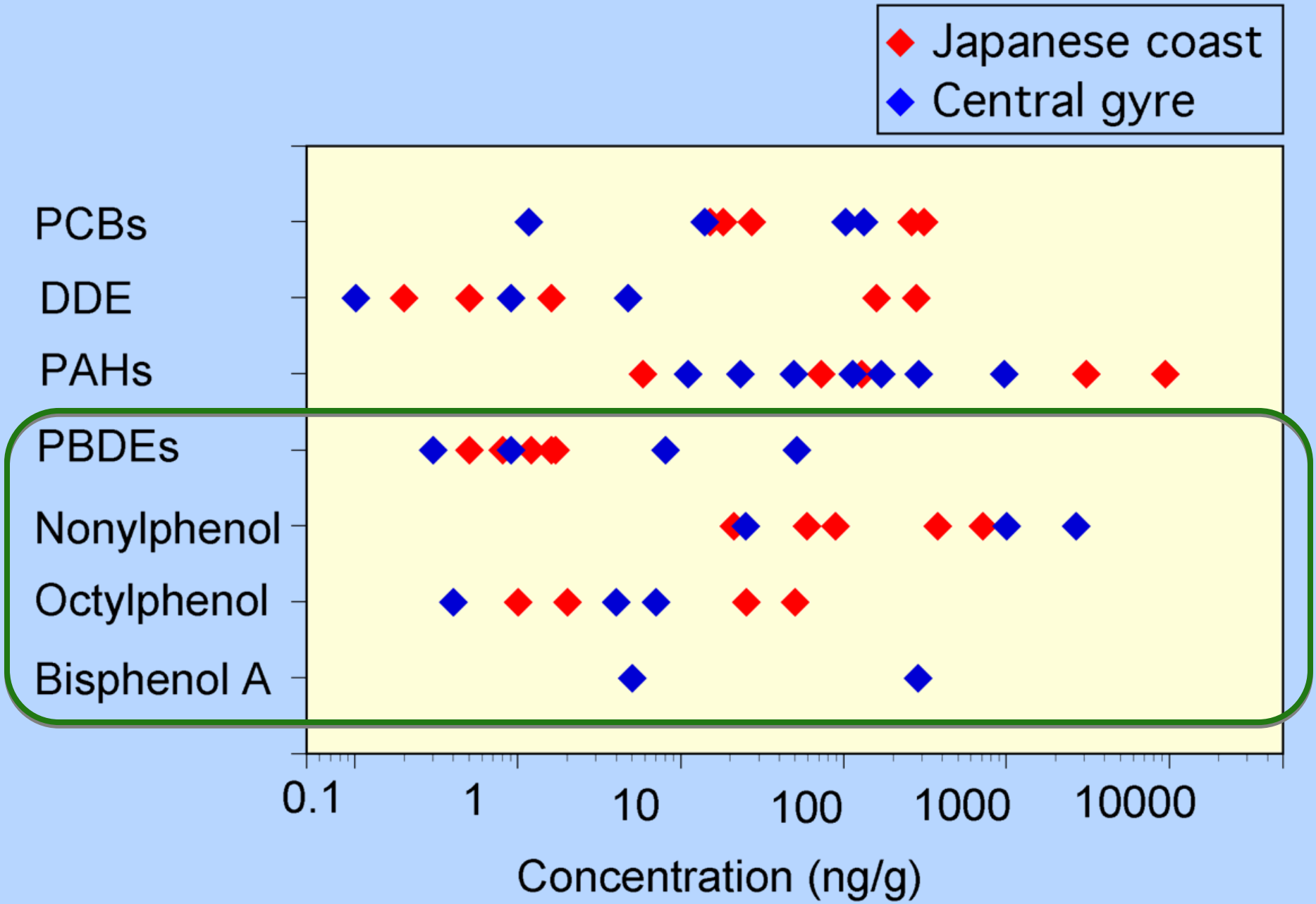


Bisphenol A

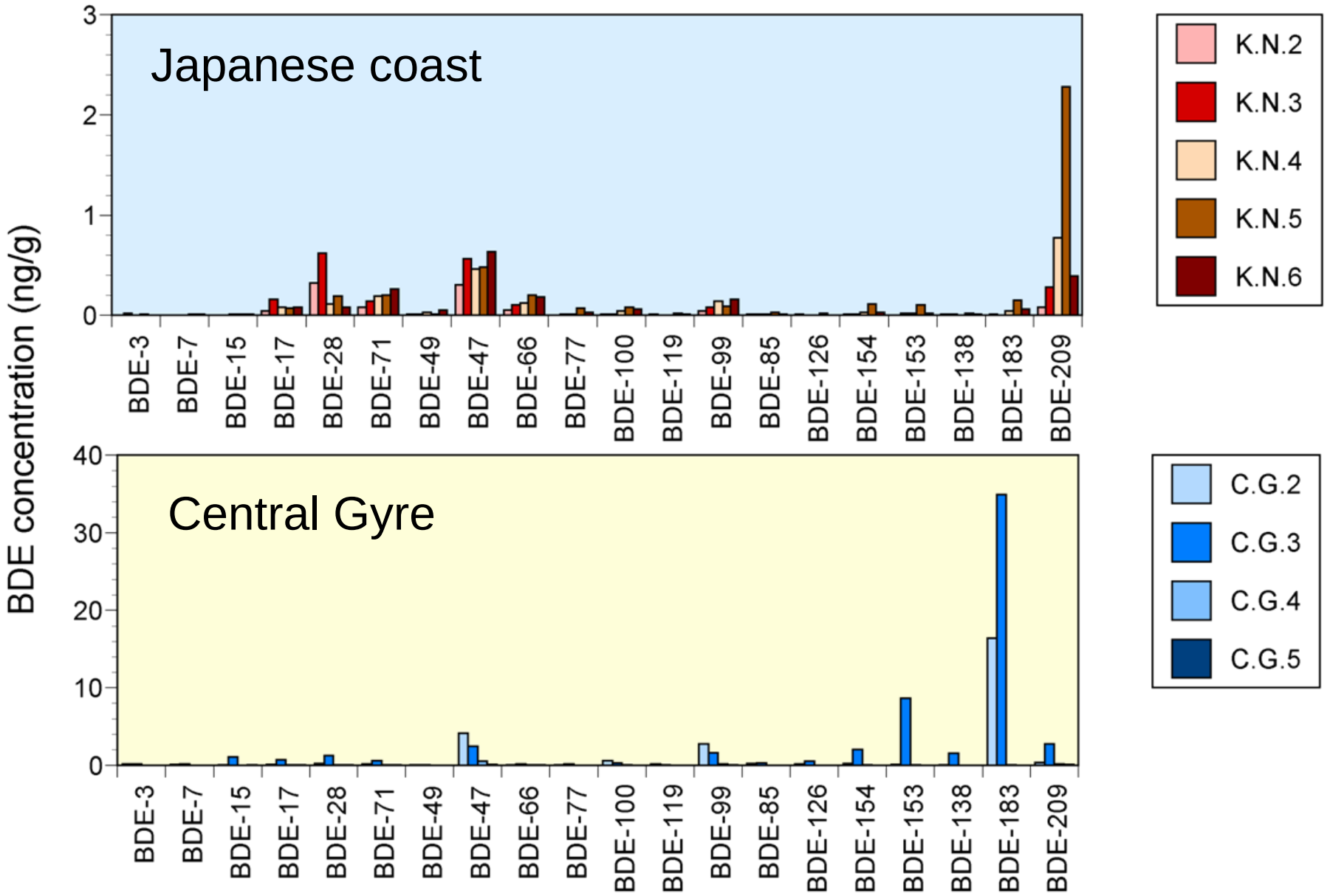


Polybrominated diphenyl ethers (PBDEs)

Broad-spectrum of contaminants in marine plastic fragments



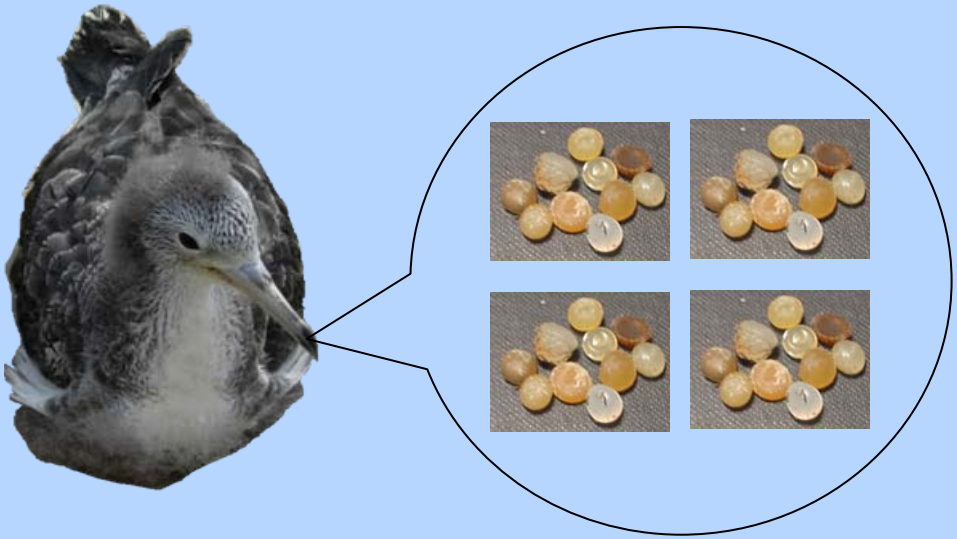
Congener profiles of PBDEs in marine plastic fragments



Conclusions of fragment study

In addition to hydrophobic pollutants, additive-derived chemicals were detected in marine plastic fragments.

3. Potential transfer of organic micropollutants from marine plastics to seabirds.



Effects of the plastic-derived contaminants on marine organisms

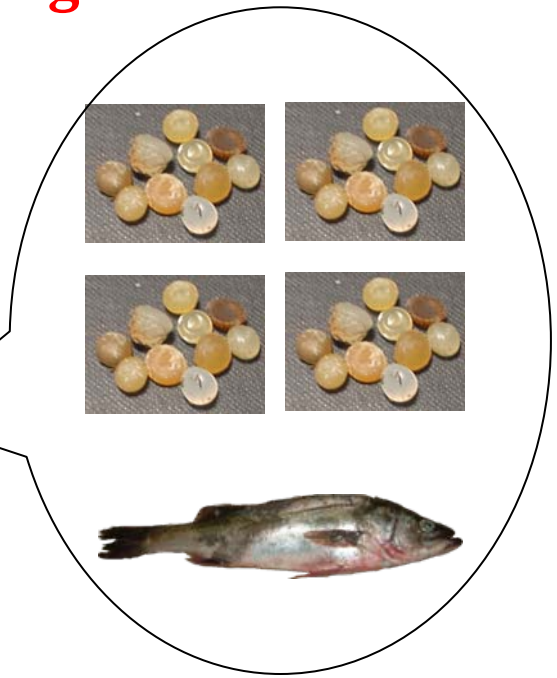
Many steps to know :

1. Are the contaminants desorbed to digestive fluid?
2. Are the contaminants transferred to the biological tissue?
3. Are the transferred amounts larger than contaminants load from natural food?
4. Do the amounts of the contaminants affect the endocrine system of the organisms?

Feeding Experiment using chick of seabird

Conducted by Ms. Rei YAMASHITA

Plastic-feeding



Blood

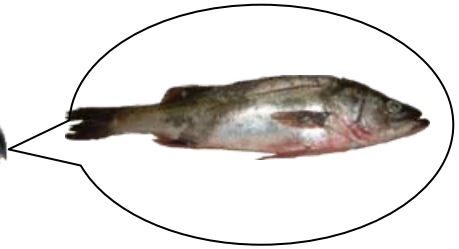
Preen Gland Oil

Liver
Muscle
Adipose

40 days later

Control

Streaked Shearwater

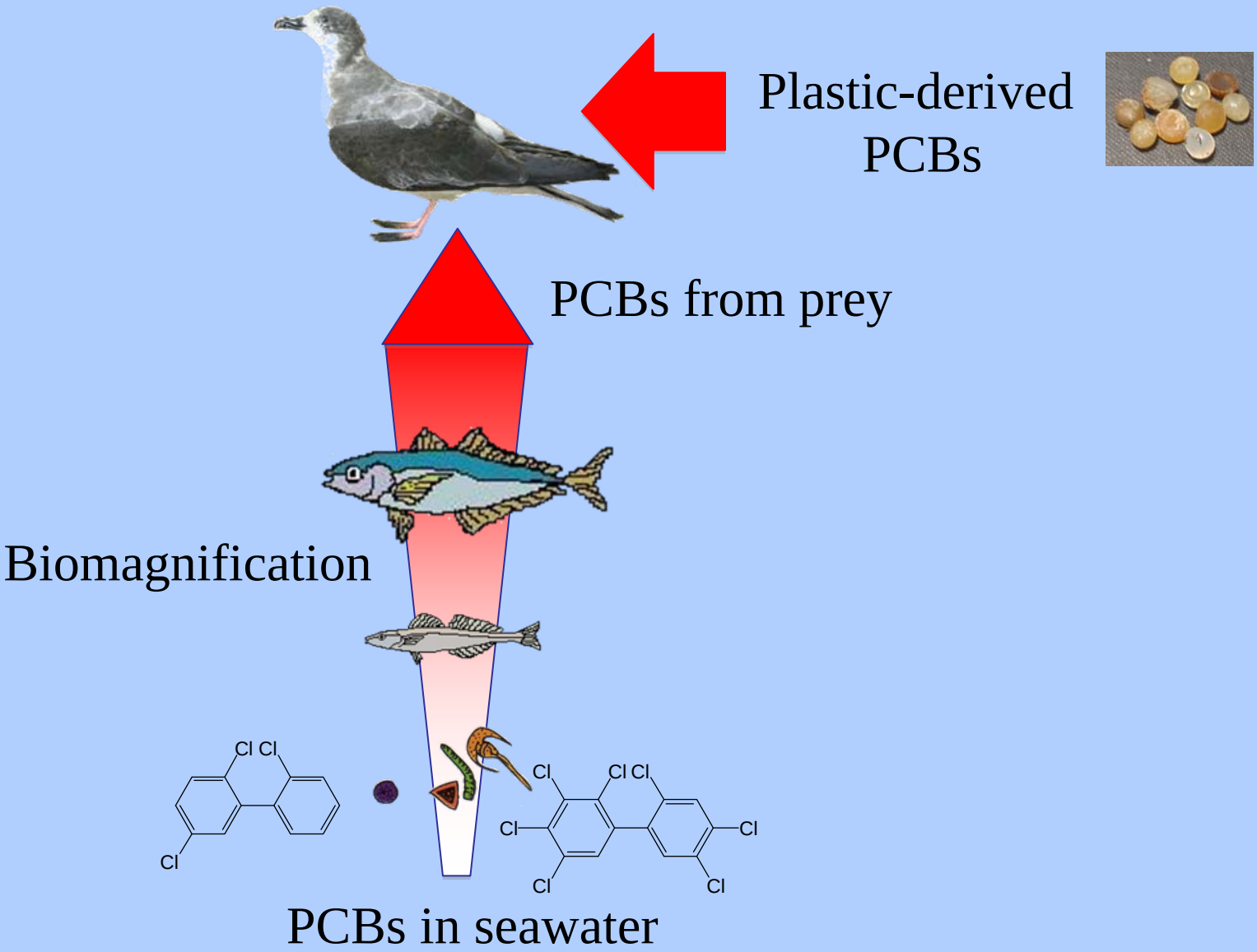


Blood

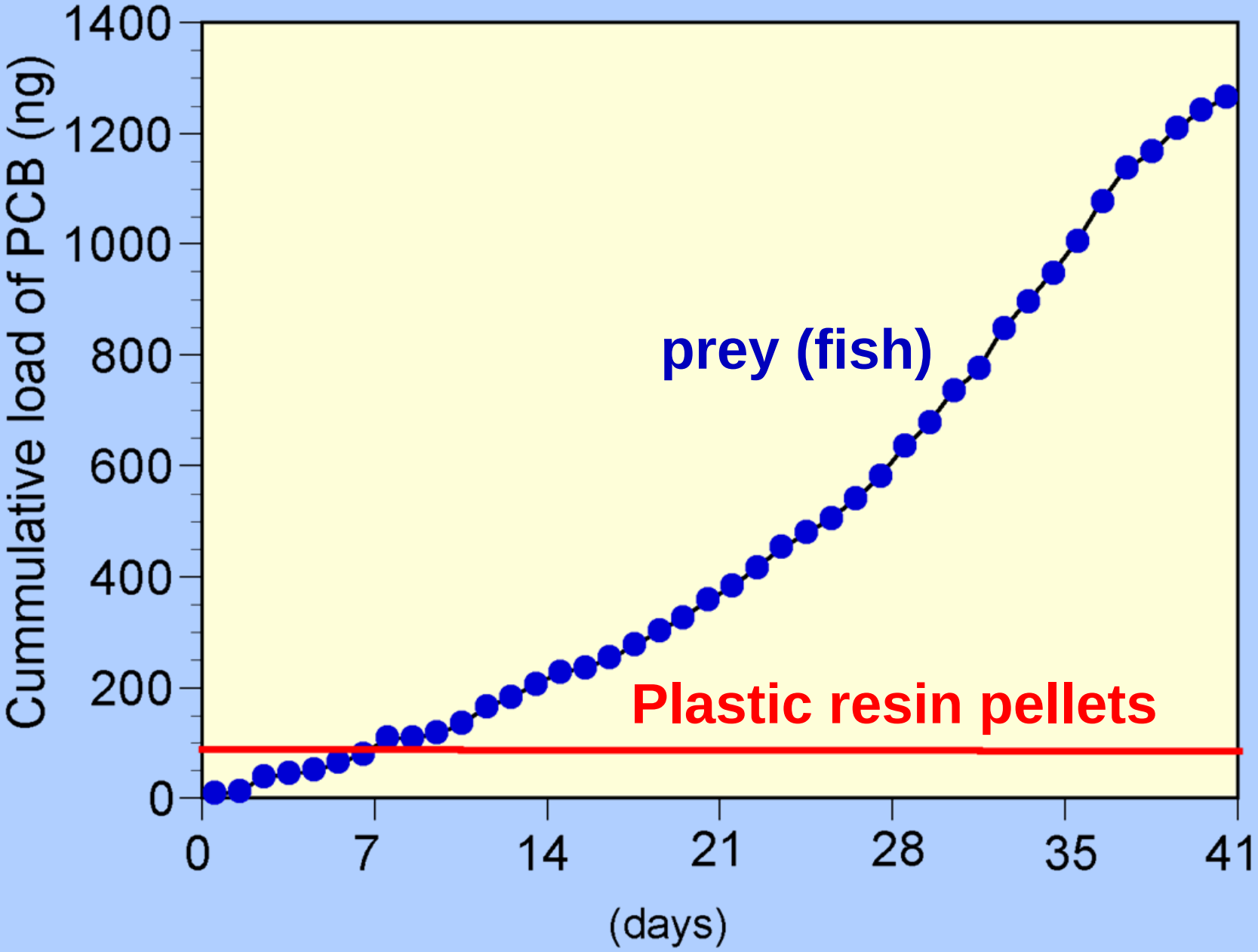
Preen Gland Oil

Liver
Muscle
Adipose

Exposure of contaminants from plastics and prey



Exposure of PCBs from plastics *vs*. fish



POPs monitoring by using **Preen Gland Oil**

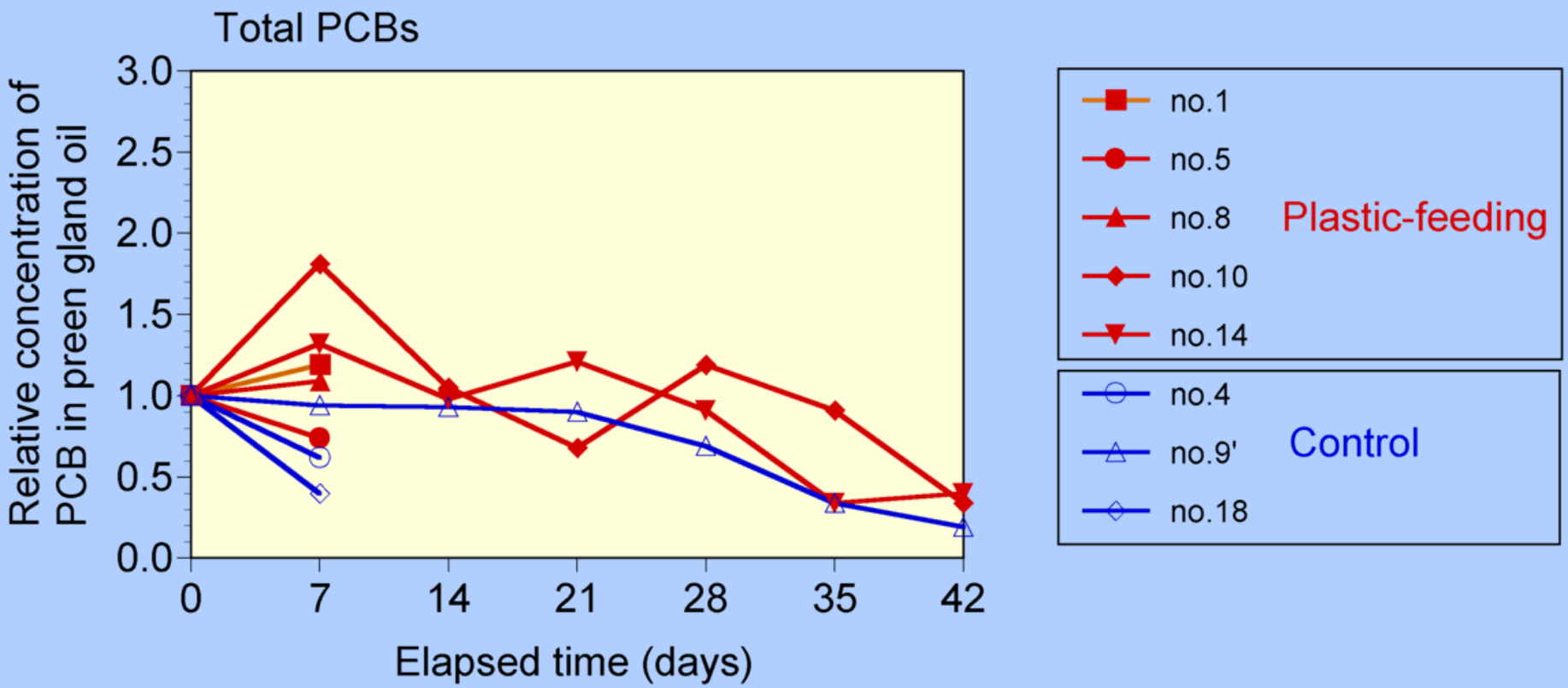
: non-invasive approach

Environ. Sci. Technol. 2007, *41*, 4901–4906

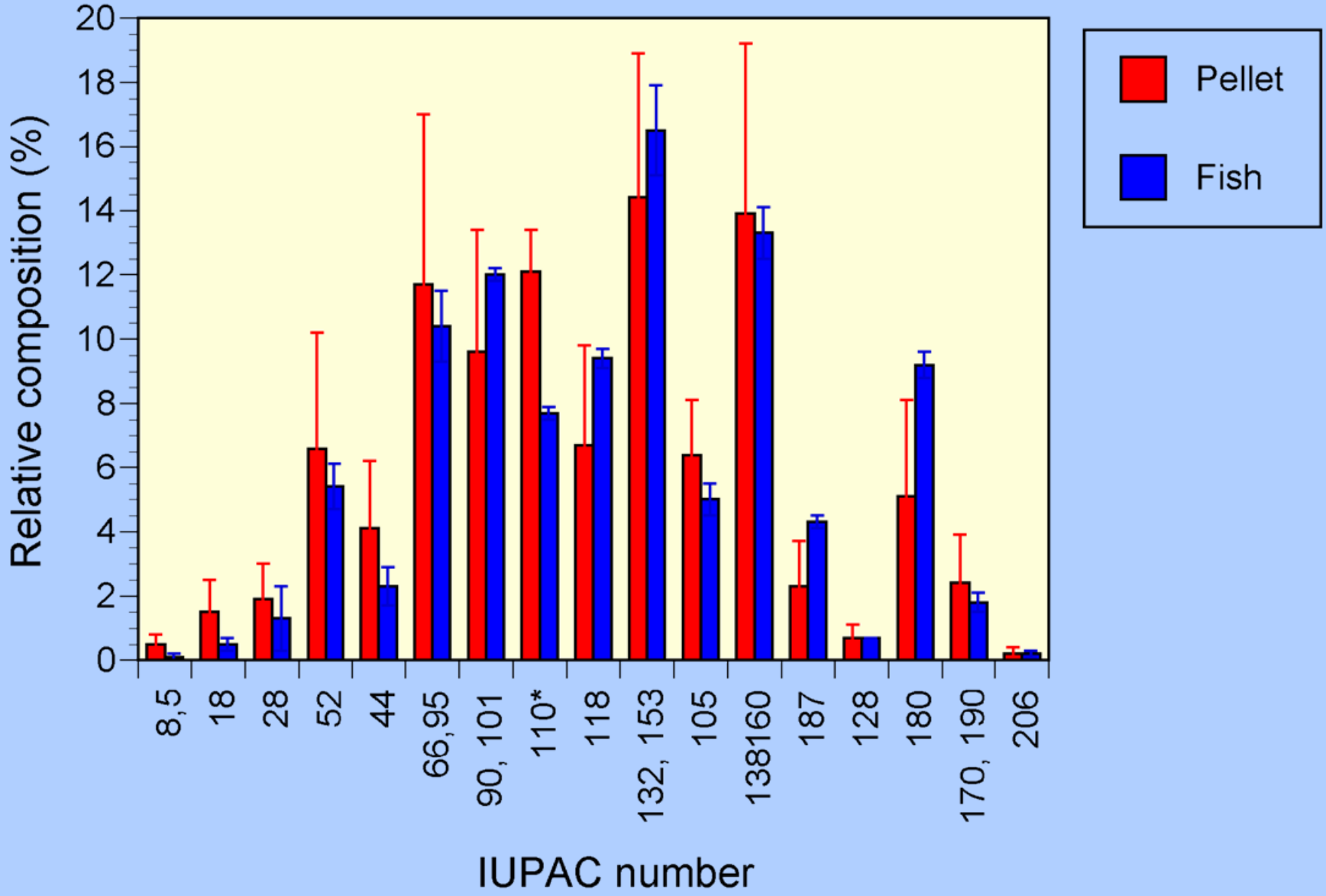
Evaluation of Noninvasive Approach for Monitoring PCB Pollution of Seabirds Using Preen Gland Oil

REI YAMASHITA,[†] HIDESHIGE TAKADA,[*,‡]
MICHIO MURAKAMI,[‡]
MASA-AKI FUKUWAKA,[§] AND
YUTAKA WATANUKI[†]

Time-course of PCBs in preen gland oil during feeding experiment



Congener profiles of PCBs : Plastic pellets *vs*. Fish



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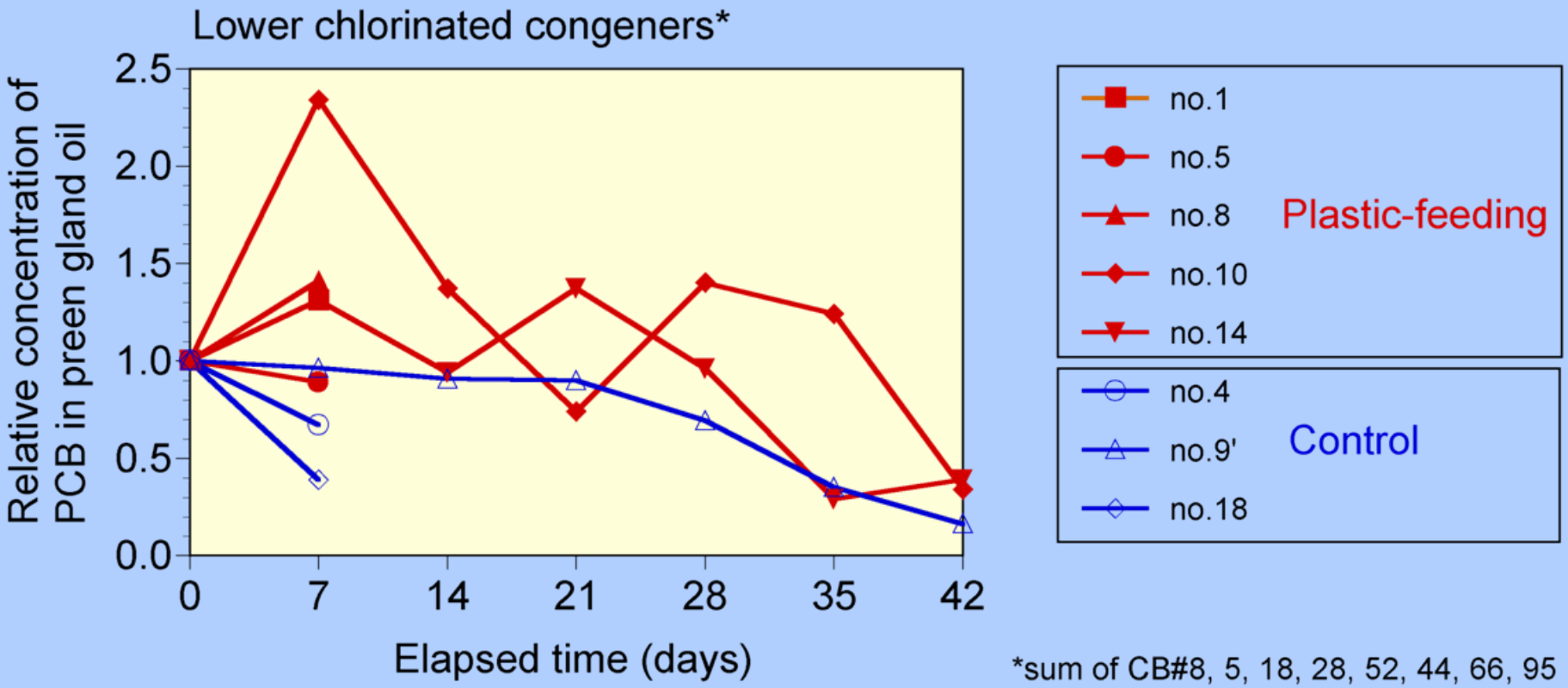
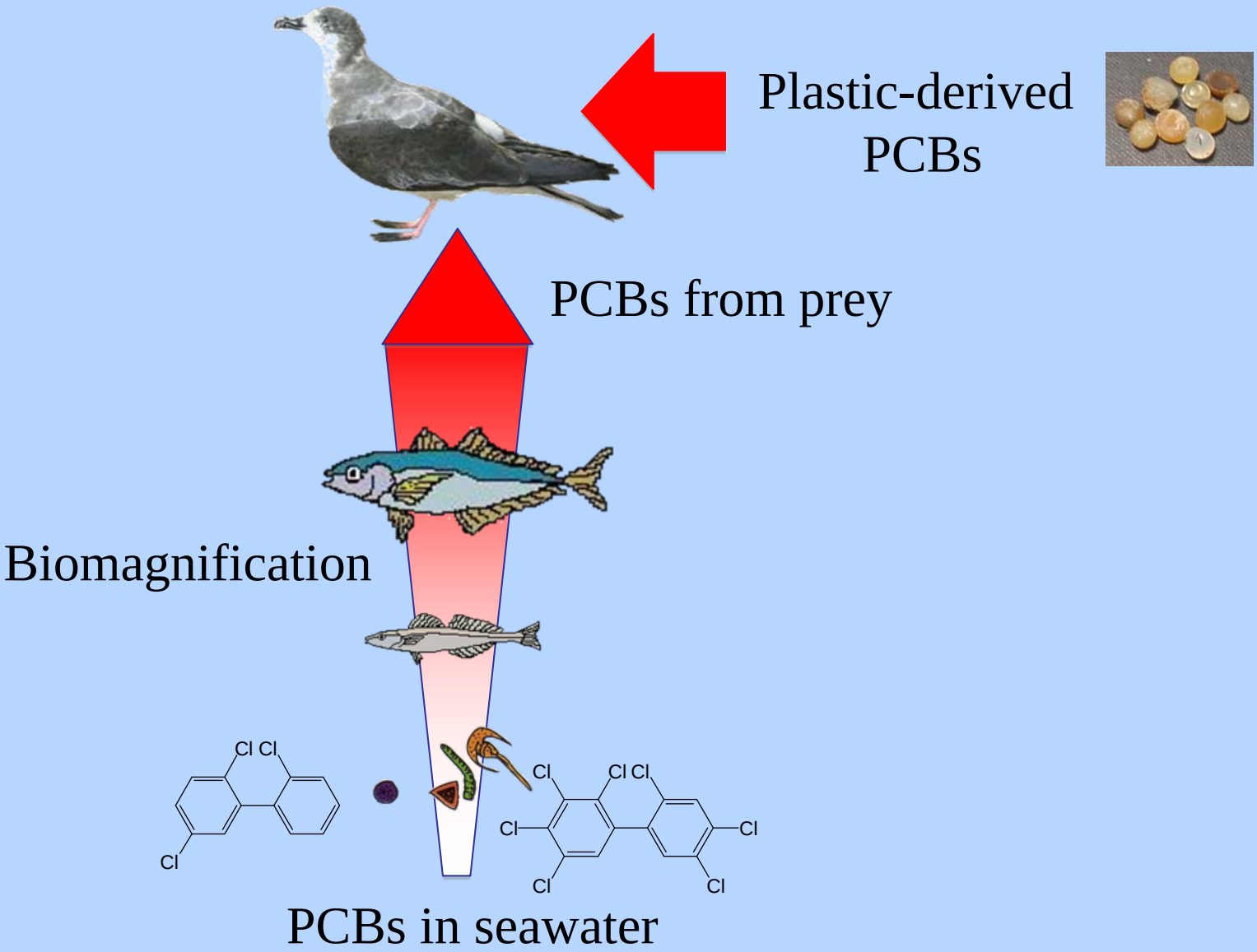


*sum of CB#8, 5, 18, 28, 52, 44, 66, 95

Exposure of contaminants from plastics and prey



Conclusions and Future directions

- ✓ Transfer of PCBs from ingested plastics to seabird tissue was suggested.
- ✓ However, due to exposure of biomagnified PCBs from prey, the evidence was not so concrete.

Future studies should focus on

- Seabird uptaking more plastics such as Fulmars.
- Lower-trophic-level organisms.
- Contaminants with less biomaginification.

PBDEs are less biomagnified than PCBs

Submitted to *Mar. Pollut. Bull.*

Bioconcentration and biomagnification of polybrominated diphenyl ethers (PBDEs) through lower-trophic-level coastal marine food web

By Kaoruko Mizukawa, Hideshige Takada*, Ichiro Takeuchi, Tokutaka Ikemoto, Koji Ohmori, Kotaro Tsuchiya

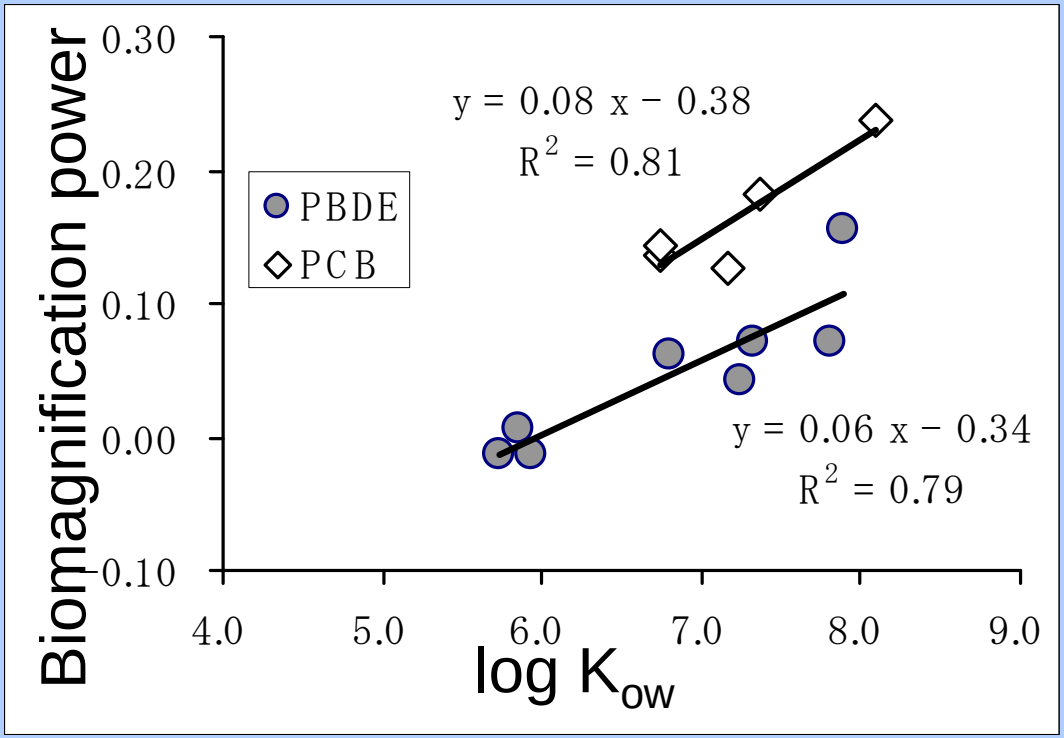
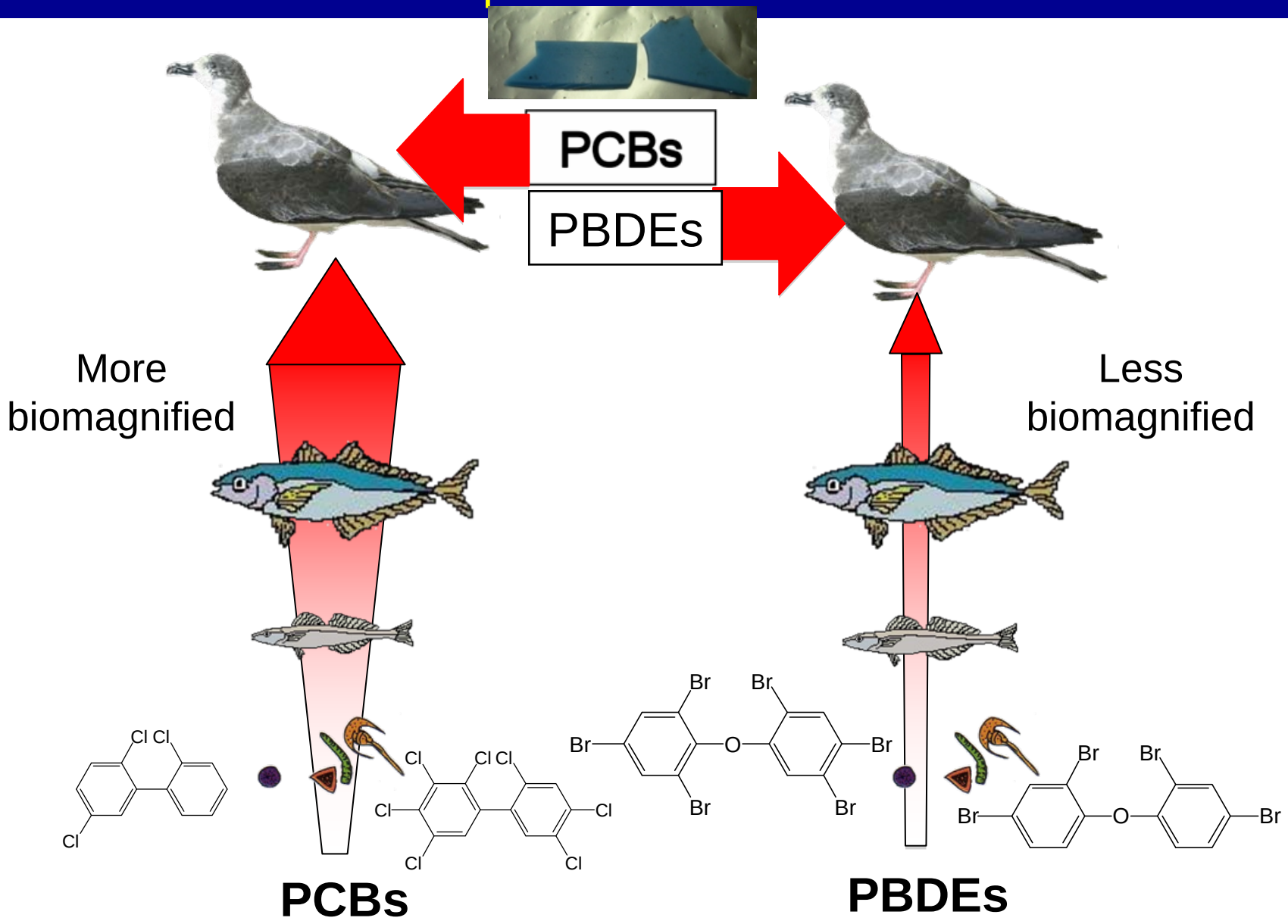


Fig. 6 Relationship between biomagnification power and K_{ow} of the individual PBDE and PCB congeners.

Plastic-derived PBDEs could have more impact on seabird exposure of contaminants



Thank you for your attention.

Call for pellets!

http://www.tuat.ac.jp/~gaia/ipw/index.html

Microplastic-pollutant interactions and their implications in contaminant transport to organisms

Dr. Emma Teuten, University of Edinburgh, Edinburgh, UK

Abstract: Uptake of hydrophobic organic contaminants (HOCs) onto plastic debris followed by transport of the sorbed contaminants to organisms has been discussed in the literature since the 1970s. While it has been unequivocally demonstrated that contaminants concentrate on plastics in the environment, little evidence exists supporting their subsequent transfer to animals. This is probably due partly to the complexity of designing experiments to effectively investigate such transfer.

On-going work at the University of Plymouth has attempted to address this issue. Transfer of plastic-bound contaminants to a typical benthic organism (lugworm; *Arenicola marina*) was modelled using equilibrium partitioning. The model results suggested that addition of plastic to the sediment would decrease the contaminant tissue concentration in lugworms. This is due to the high affinity of plastics for HOCs allowing them to act as "scavengers", thus removing contaminants from the environment and reducing the exposure of benthic organisms. However, this mechanism can only apply for plastics that are relatively "clean" and uncontaminated. Since plastics readily sorb HOCs from the environment, they are unlikely to remain clean for long. Plastics are known to accumulate on the strandline, and float in the sea-surface microlayer, where contaminant concentrations are often higher than in the bulk water. Fouling of the plastics can cause them to sink, carrying their contaminant load into the sediment, where it may ultimately increase the contaminant body burden of sediment dwelling organisms. Preliminary *in vivo* trials have demonstrated transfer of a selection of HOCs from plastics to lugworms.

Uptake of contaminants by organisms occurs by inhalation, dermal sorption and ingestion, dependant upon the organism and the physicochemical properties of the contaminant. For many organisms ingestion is the most likely exposure route for plastic-mediated uptake of contaminants. More than 180 species have been documented to ingest plastic debris, and a positive correlation between the mass of ingested plastic and the PCB concentration in birds has been observed. Since plastics are known to accumulate PCBs in the environment, this correlation supports plastic-mediated transfer of contaminants to higher organisms.

Emma Teuten, PhD, completed her PhD in organic chemistry at the University of Missouri in 2002 and then received a Dreyfus Postdoctoral Fellowship to conduct environmental chemistry at Woods Hole Oceanographic Institution. Her work there focused on the origin of halogenated organic contaminants in marine mammals. Following that she returned to the UK and did another postdoc at the University of Plymouth, where she investigated transport of contaminants to benthic organisms by microscopic fragments. She is currently working as a Research Fellow in Environmental Engineering at the University of Edinburgh, where she is looking into the potential for plastics to be used as sorbents in the removal of contaminants from the environment.

Microplastic-pollutant interactions and their implications in contaminant transport to organisms

Emma Teuten

University of Edinburgh

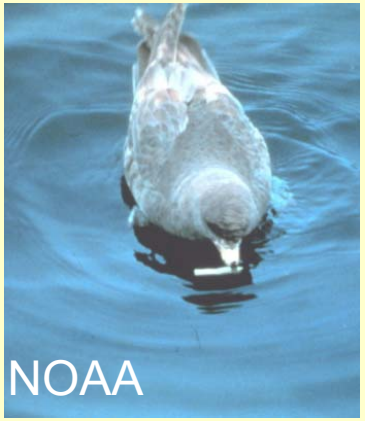
Outline

- Brief introduction
- Sorption of contaminants to plastics
  - Plastic type
  - Weathered plastics
  - Surface area
- Desorption of contaminants from plastics
- Transport of contaminants from plastics to organisms
  - Modeling
  - *In vivo* studies
- Conclusions & unanswered questions

Numerous Organisms Eat Plastic

Macroscopic fragments

- Birds, fish, turtles, seals



Fragmentation

Microscopic fragments

- Lugworms
- Barnacles
- Sandhoppers
- Mussels

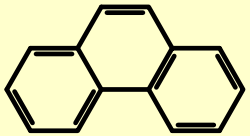
Thompson et al, Science, 2004

Previous reports of environmental contaminants sorbed to plastics

1972	− Carpenter *et al.*	PCBs
2001	− Mato *et al.*	PCBs, DDE, nonylphenols
2005	− Endo *et al.*	PCBs
2007	− Rios *et al.*	PCBs, DDTs, PAHs, aliphatic hydrocarbons

Sorption of contaminants to plastics: A lab study

Phenanthrene:



Priority pollutant (US EPA)

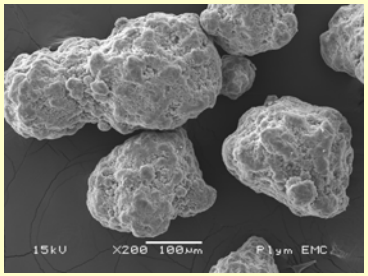
Sources: combustion & oil spills

Carcinogenic

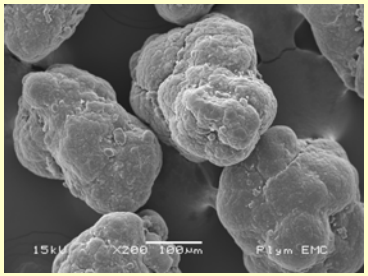
log K_{ow} = 4.6

Polymers (200-250 µm)

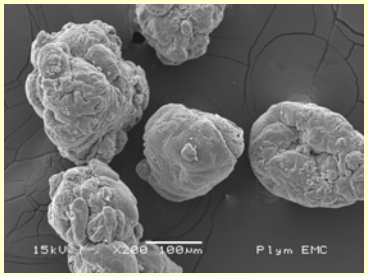
Polyethylene



Polypropylene



Polyvinyl chloride



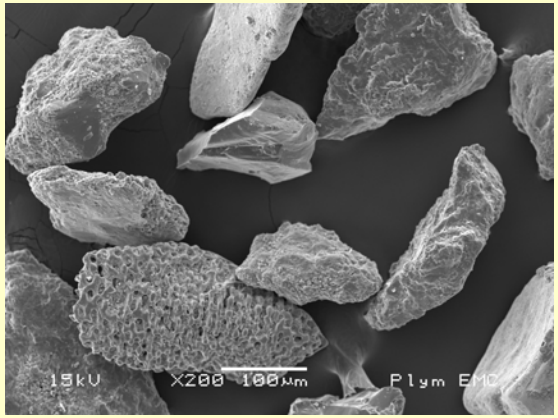
Sediment Samples

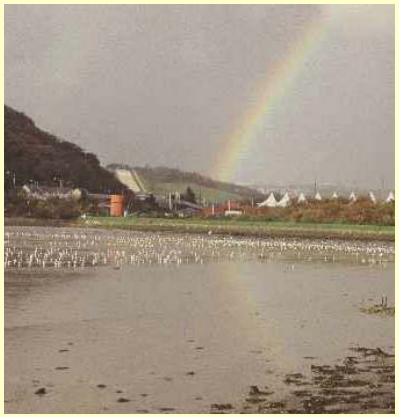
Collected in Devon, SW England

Mothecombe Estuary

Predominantly sand (median grain size = 190 μm)

OC = 0.18 ± 0.09%

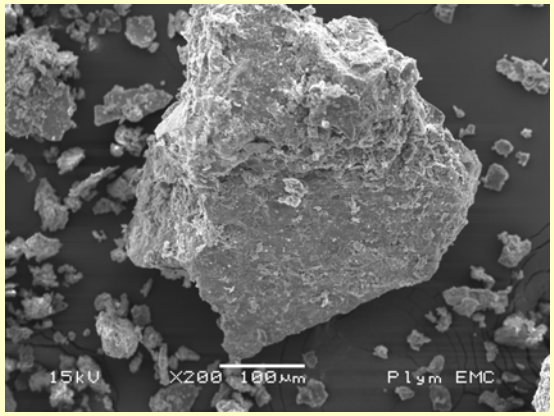




Plym River Valley

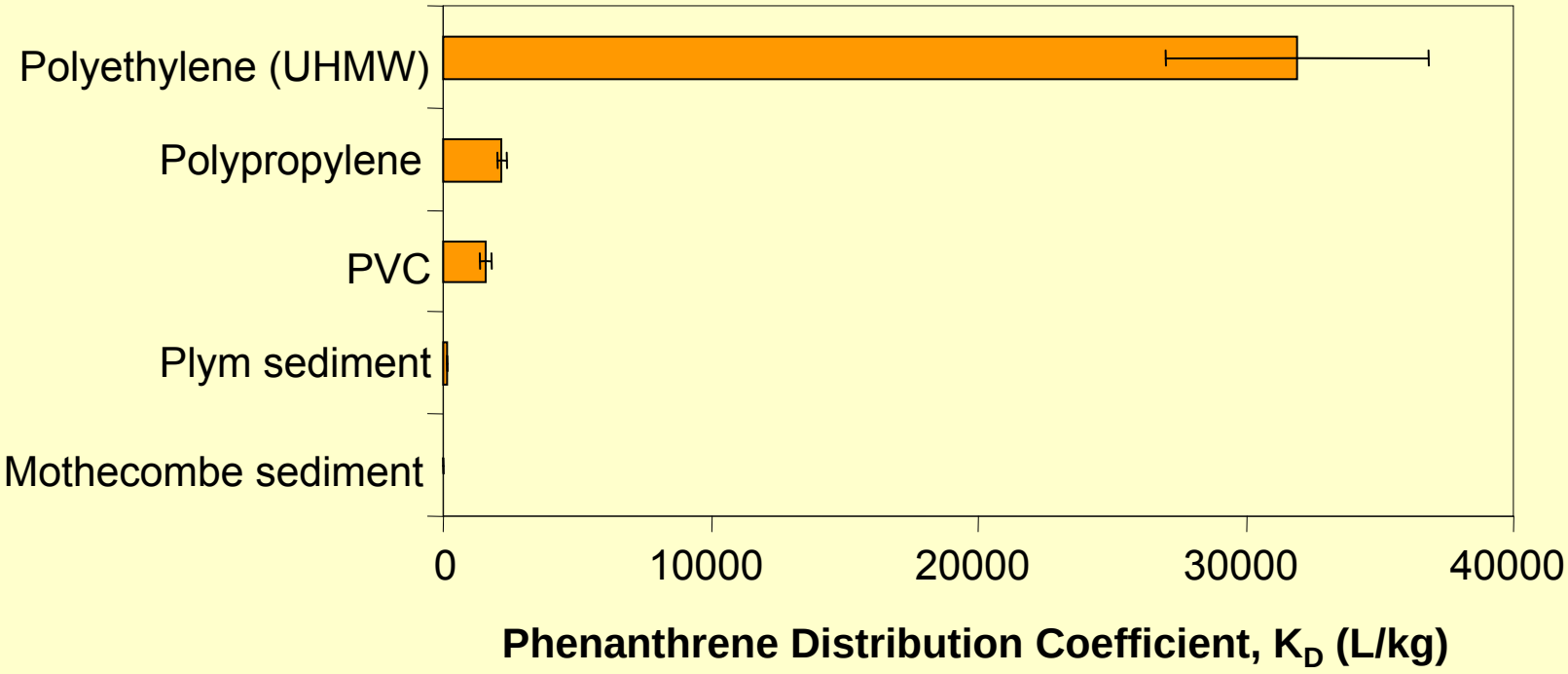
Predominantly silt (median grain size = 35 μm)

OC = 0.67 ± 0.14%



Sorption of phenanthrene to plastics and sediments

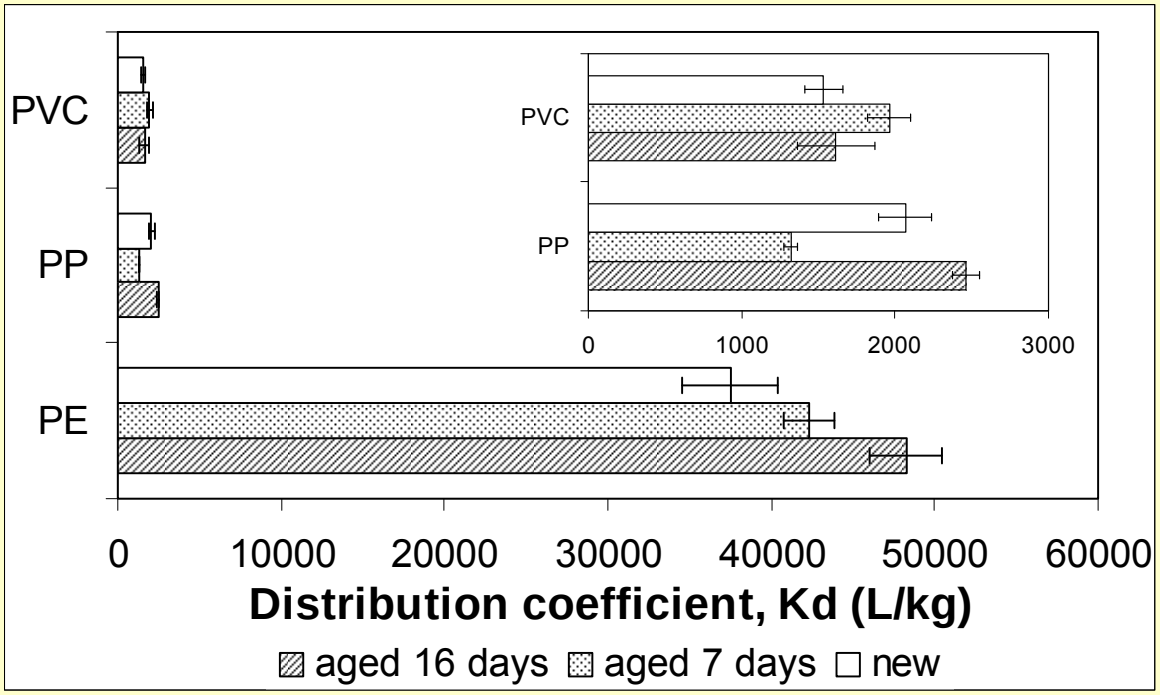
- In seawater (filtered, autoclaved)
- 24 h equilibration, ≥3 replicates
- Environmental concentrations (0.6 to 6.1 µg/L)
- Sorption isotherms at 18 ºC



Teuten *et al.* EST, 2007

UV weathering affects phenanthrene sorption to plastic

- **Cracking** → increased surface area → increased uptake
- **Oxidation** → increased polarity → decreased uptake



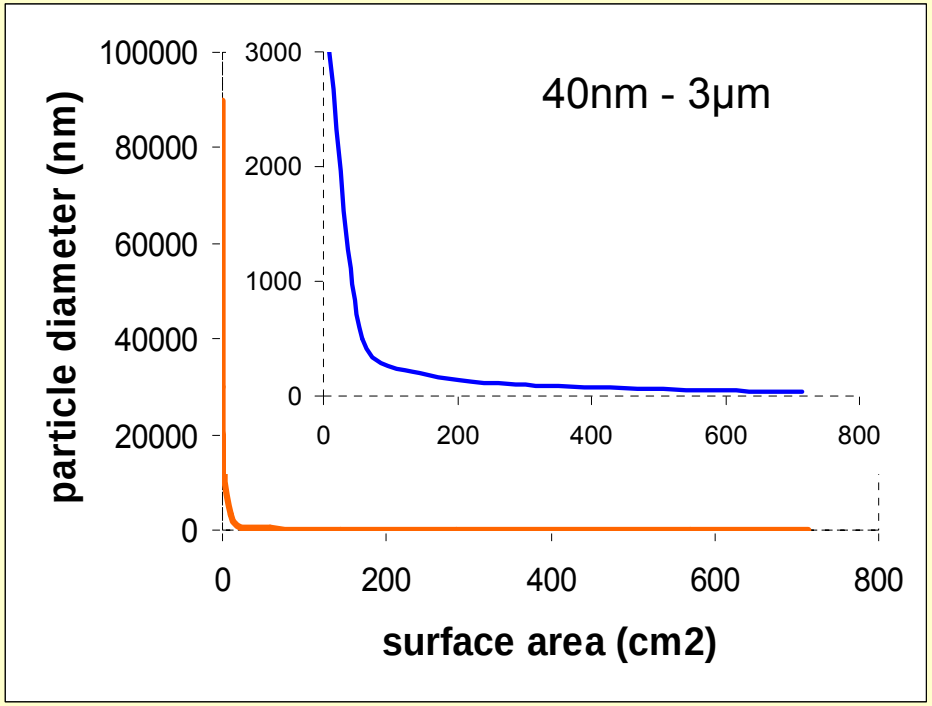
- Plastics exposed to natural wavelength UV light for the equivalent of 7 and 16 months
- Sorption of phenanthrene from seawater

Teuten *et al.*, Phil. Trans Royal Soc, in review

The effect of particle size on contaminant uptake

- Constant mass of plastic
  - Fragmentation gives more particles
  - Increased surface area
  - Greater contaminant sorption?

Diameter (nm)	No. spheres /g	Surface area (cm^2)
50,000	1.5×10^{7}	0.6
5,000	1.5×10^{10}	6
500	1.5×10^{13}	57
50	1.5×10^{16}	571

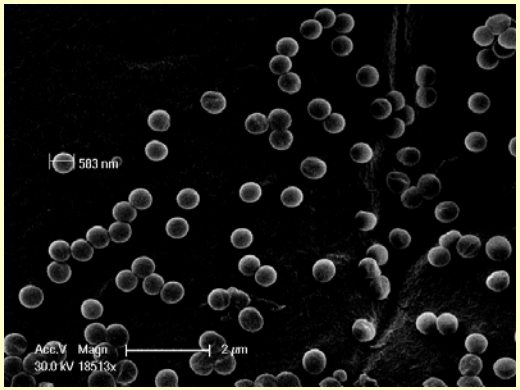


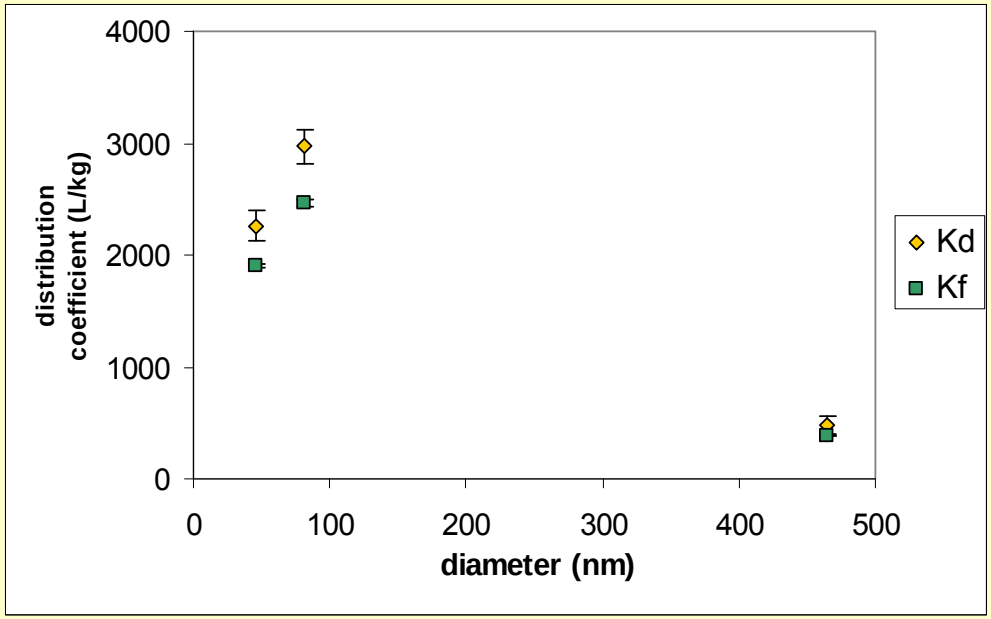
Effect of particle size on sorption to polystyrene

Estradiol:

- Female sex hormone
- Potent endocrine disruptor
- Log K_{ow} ~ 2.6

Sorption from artificial fresh water

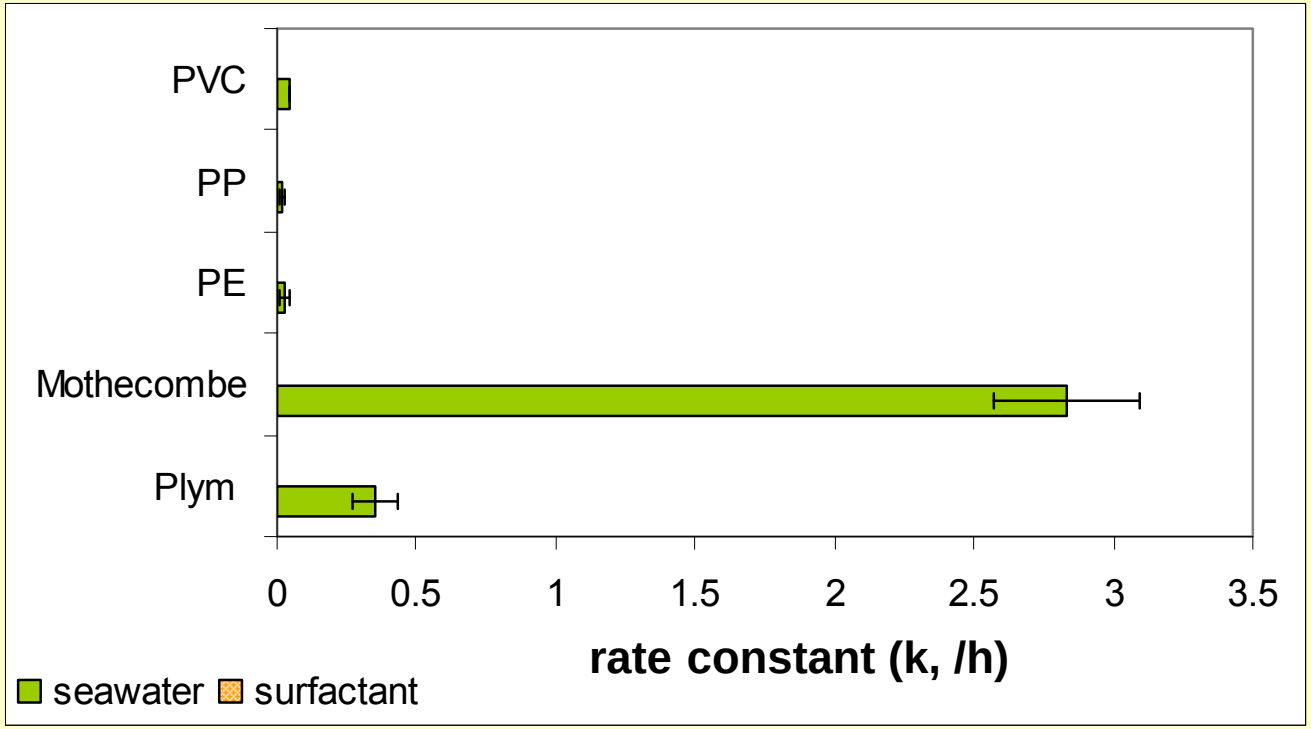




Teuten, unpublished

Desorption of phenanthrene from plastics and sediments

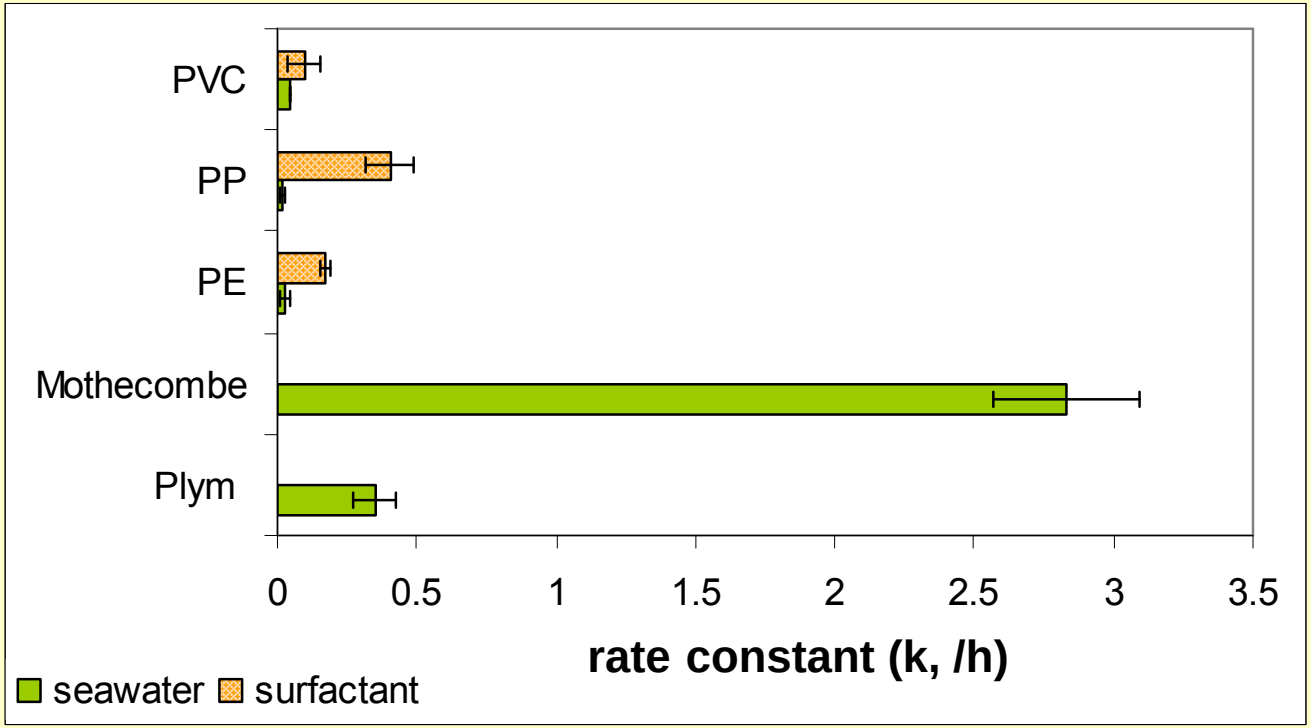
- Sorb PHE to plastic from seawater
- Comparison of desorption rates
  - (i) Seawater



Teuten *et al.* EST, 2007

Desorption of phenanthrene from plastics and sediments

- Sorb PHE to plastic from seawater
- Comparison of desorption rates
  - (i) Seawater; (ii) sodium taurocholate (surfactant)



Teuten *et al.* EST, 2007

Can plastics transport contaminants to organisms?

Lugworm, *Arenicola marina*

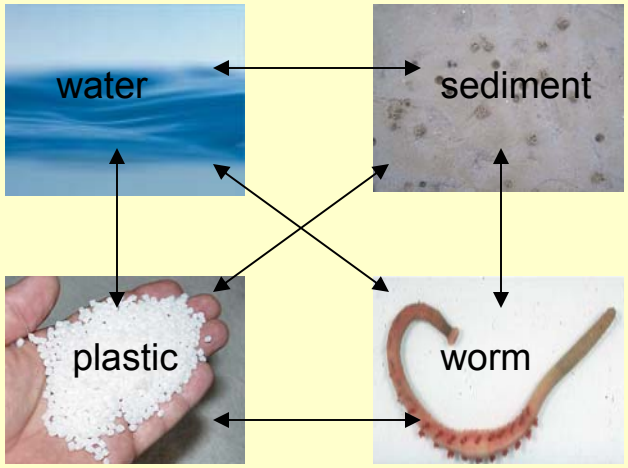
- Important deposit feeder
- Base of the food chain
- Eaten by fish that humans eat
- Ingests microscopic plastic

Investigation methods:

- Equilibrium partitioning modeling
- *In vivo* studies

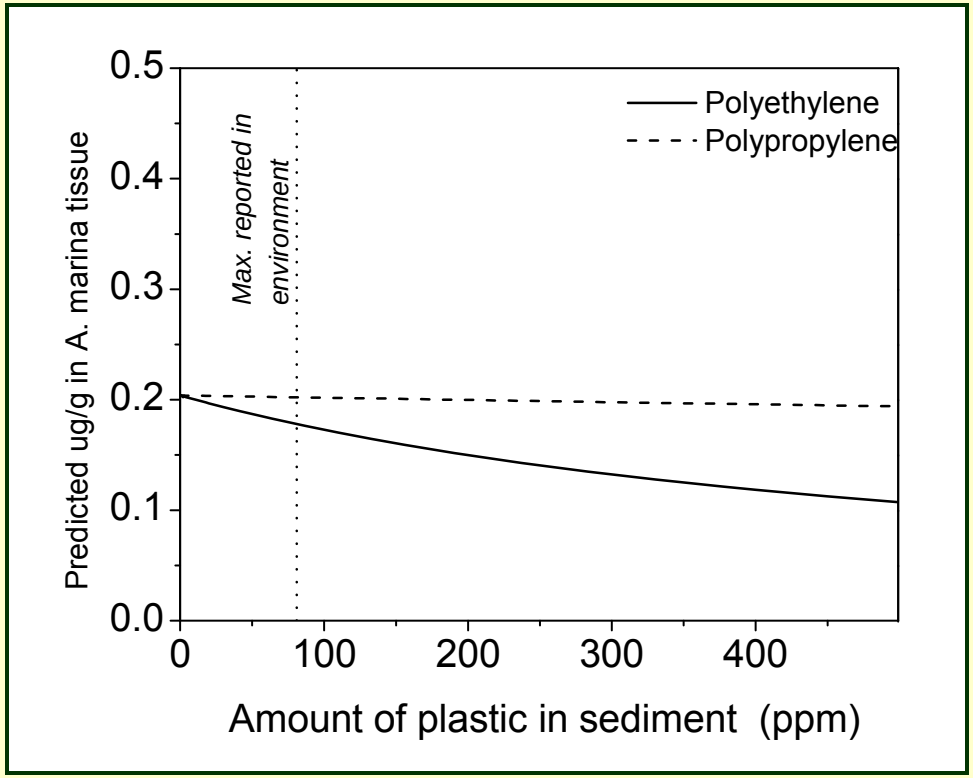
Lugworm feeding strategy

- Strips organic matter from ingested sediment
- Enhanced by gut surfactants
- Contaminant uptake is explained by *equilibrium partitioning*
- Assumes equilibrium is reached between all environmental compartments



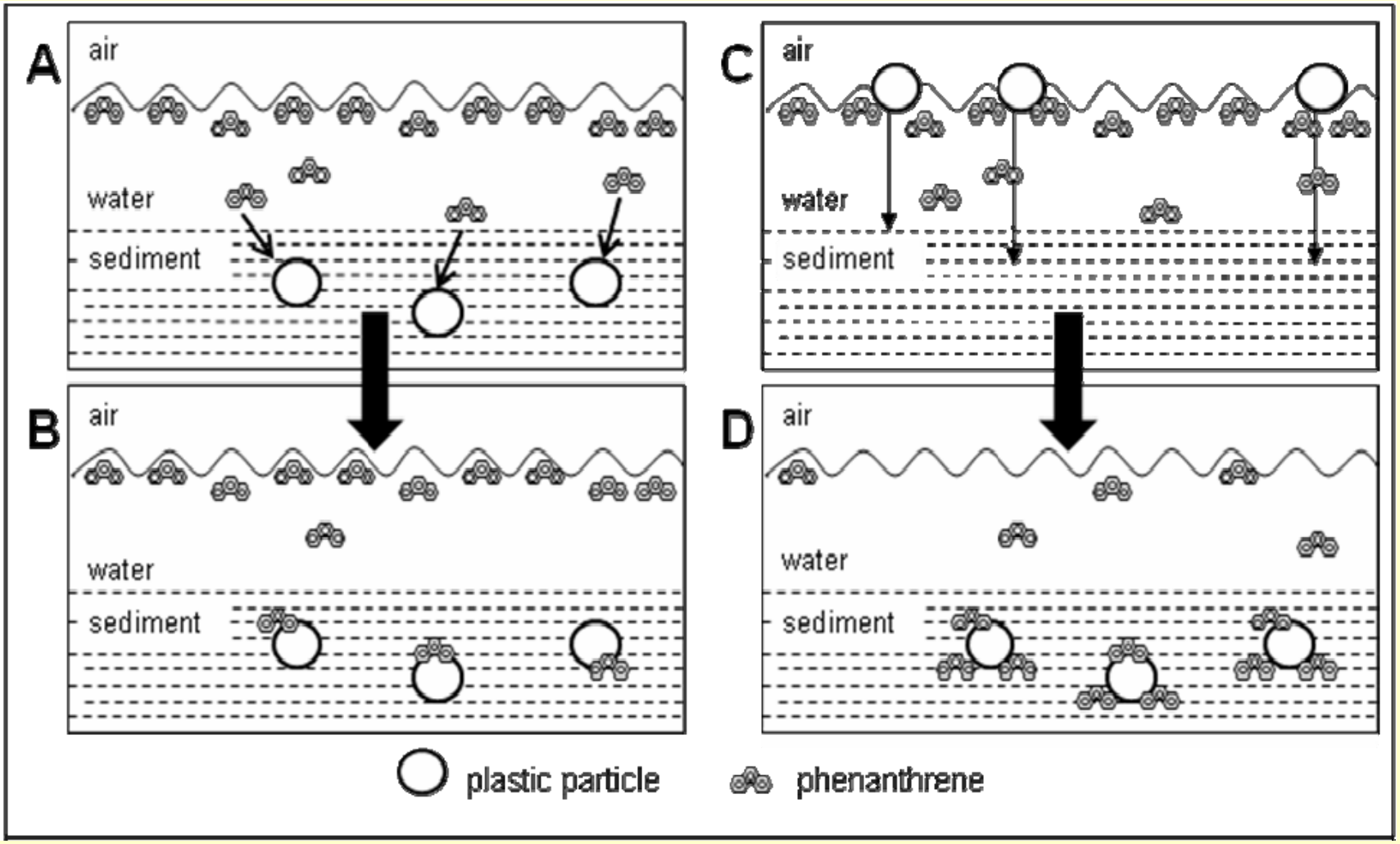
Effect of plastic on benthic phenanthrene concentrations

- Addition of ‘clean’ plastic to sandy sediment



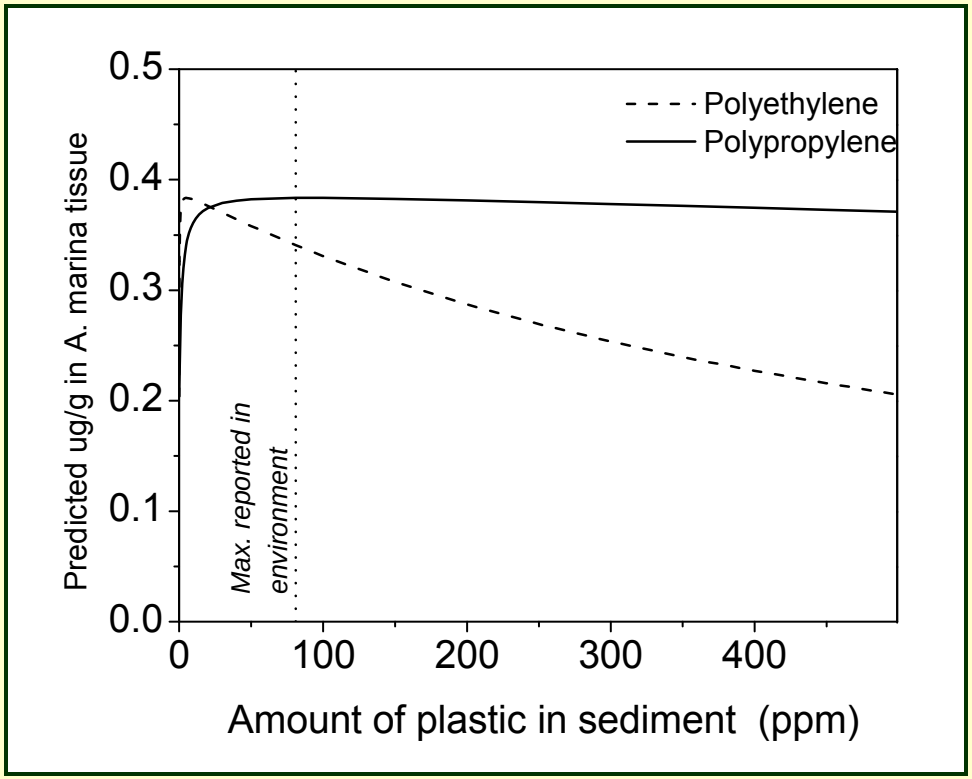
Teuten *et al.* EST, 2007

Phenanthrene sorption schematic



Effect of plastic on benthic phenanthrene concentrations

- Addition of ‘contaminated’ plastic to sediment



Equilibrium model

- First plastic equilibrates with PHE in SML
- Plastic is transported to sediment
- PHE-sorbed plastic equilibrates with the sediment, porewater and organism
- Uses environmental PHE concentrations reported at Chesapeake Bay (Hardy *et al*., *Mar. Chem.* **1990**)

Teuten *et al.* EST, 2007

Preliminary *in vivo* studies: methodology

- Sorption of contaminants to plastic (PVC)
  - Contaminant dissolved in ethanol
  - Allow ethanol to evaporate
- Mix plastics with sand
- Add seawater
- Add nutritional supplement if necessary
  - For expts using organic-free sand
- Add lugworms after 24h
- 10 – 14 day exposure
  - Natural light cycle, with aeration
- Depurate worms before analysis

Preliminary *in vivo* studies

Unpublished figure removed

- 10 day exposure of phenanthrene to lugworms using natural sediment
- 10% PVC by mass
- Solvent extraction; GC-MS analysis

Ylva Olsen, unpublished

Experimental uncertainties

- No mass balance
  - Only [PHE] in worm was initially determined
  - Contaminant loss?
- Uncharacterised natural sediment
- Extraction efficiency not determined
- Phenanthrene concentrations in sediment determined using archived sediment

More preliminary *in vivo* studies

- Using sand from Fisher (organic free)
- Range of contaminants
  - Phenanthrene – *PAH*
  - Nonylphenol – *surfactant degradation product*
  - Tetrabromodiphenyl ether (TBDE) – *flame retardant*
  - Triclosan – anti-microbial
- Rigorous quantitative analysis
  - Standard reference materials
  - Recovery of spiked contaminants

Transfer of contaminants from plastic to lugworms

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- 14 day lugworm exposure trials using organic-free sand
- 5% PVC by mass
- Soxhlet extraction; contaminant analysis by GS-MS

Stewart Niven & Mark Browne, unpublished

Control experiments

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Stewart Niven & Mark Browne, unpublished

Experimental uncertainties

- No mass balance
  - aqueous phase concentration not determined
- Contaminant sorption methodology
  - Using organic solvent
  - Does the solvent affect the PVC, e.g. swelling?
- Environmental relevance of using new plastics?

Application of equilibrium partitioning to our *in vivo* studies

- Using data second *in vivo* study (Stew & Mark)
- Know conditions for each system
- Equilibrium concentrations calculated using equilibrium partitioning

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Unpublished data

Conclusions

- Plastics readily sorb phenanthrene from seawater
  - (PE >> PP ≈ PVC >> sediment)
- Higher uptake of estradiol onto nano-plastics (<100nm)
- Clean plastic in sediment decreases exposure of lugworms to contaminants – *scavenging effect*
- Plastic may transport additional contaminants to sediments
- Difficulty explaining *in vivo* studies with equilibrium partitioning

Many unanswered questions

- What is the effect on other organisms with different feeding strategies?
- Do gastro-intestinal conditions affect release of contaminants from plastics?
- How does biofouling affect contaminant sorption/ transport?
- What are the consequences when plastics are retained inside animals?
- And many more…

Acknowledgements

- University of Plymouth:

  Richard Thompson, Steve Rowland, Mark Browne, Stewart Niven, Ylva Olsen, Geoff Millward, Andy Tonkin, Jeremy Clark, Tamara Galloway, Ben Smith, Paul Sutton, Alan Tappin
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  Jim Weidman, Fred Staff
- University of Edinburgh:

  Andrea Schäfer, Peter Grant, Peta Neal, Alan Simm, Zuzanna Kamasa
- Financial Support:

  Leverhulme Trust, University of Edinburgh

SESSION IV: EFFECT OF OCEANIC SMALL PLASTIC DEBRIS ON BIOGEOCHEMICAL CYCLING OF POPS

Role of microplastics on transport and fate of POPs

Dr. Rainer Lohmann, University of Rhode Island, Providence, RI, USA

Abstract: Results from recent ocean cruises covering the Arctic (2004), Atlantic (2006) and Pacific (2007) Ocean are presented for different POPs. Polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were simultaneously measured in air and surface seawater between 49° N and 25° S in the open Atlantic Ocean. Broad latitudinal trends were observed with the lowest PAH and PCB air concentration in the South Atlantic and the highest off the west coast of Africa. The unexpectedly high concentrations off NW Africa were discussed assessing the possible contribution of the emerging oil industry along the African shore, the role of biomass burning and natural sources of PAHs. Correlations of PAHs' partial pressures versus inverse temperature were not significant, in contrast to results for PCBs from the same transect. This could have been due to the importance of ongoing primary sources for PAHs combined with shorter atmospheric life-times. Ratios for anthracene and phenanthrene were <0.3 in the remote tropical Atlantic, suggesting net volatilization. PCB concentrations were highest in Europe and the lowest in the Arctic. Fractionation was observed for PCBs in seawater with the relative abundance of PCB 28 and 52 increasing and that of the heavier congeners decreasing with latitude. Comparison with other data from cruises in the Atlantic and Arctic Ocean since 1990 indicate little change in PCB air concentrations. On average, deposition dominates over volatilization for PCBs in the Arctic region with a strong increase in the middle of the transect near the marginal ice zone (78-79 °N), possibly caused by ice melting. During a 2006/2007 cruise on the Pacific, gas-phase PCBs were highest in the Northern Hemisphere (NH), and decreased towards the equator. In the remote South Pacific, concentrations declined to <10 pg/m^3 for individual PCBs. In the surface water, concentrations of PCBs decreased from >2 pg/L per congener in the NH to ~1 pg/L in the S-Pacific. Dissolved PCBs in the S-Pacific gyre were higher than those reported from the S-Atlantic, possibly due to the extremely low biological productivity and removal fluxes from the S-Pacific gyre's surface waters.

Rainer Lohmann, PhD, received his PhD in Environmental Chemistry from Lancaster University, England (UK) in 2000. He then joined the Massachusetts Institute of Technology as a postdoctoral fellow, and moved to the Research Center for Ocean Margins (Bremen, Germany) as a fellow for most of 2004. Since November 2004 he has been Assistant Professor in Oceanography at the University of Rhode Island's Graduate School of Oceanography. His current research interests are: the black carbon cycle and its effects on the (bio)availability of organic pollutants, the global fate of POPs and the use of passive samplers to measure the activities of organic compounds in air, water and sediment.

Role of microplastics on transport and fate of POPs

NOAA – UW Tacoma workshop in microplastics
Sept 9-11

Rainer Lohmann

Graduate School of Oceanography (GSO), University of Rhode Island

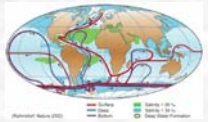
and many others

outline

- Some background on global sources and sinks of PCBs

POPs

- Oceans as sinks of POP, e.g.
  - Physical pump
  - Biological pump
  - Case studies: Atlantic, Arctic and Pacific



- Role of Microplastics?

What are POPs?
Are microplastics POPs?

Persistent Organic Pollutants – microplastics

molecules	*versus*	particles
Persistence		YES
Potential for LRT		YES
Bioaccumulation		?
Adverse effects		?

- POPs driven by bioaccumulation (Arctic)

Role of microplastics on global fate of POPs

The sorption of POPs to Microplastics is reversible

- **Hypothesis 1**: Microplastics will act as carriers of pollutants

For most POPs, atmospheric transport dominates

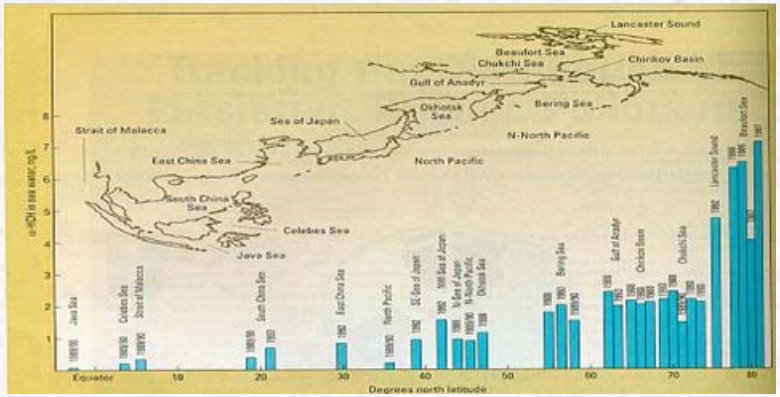
- **Hypothesis 2**: Microplastics matter as a source only where LRAT is low / (air-water) are near equilibrium

Microplastics are stable in the surface water

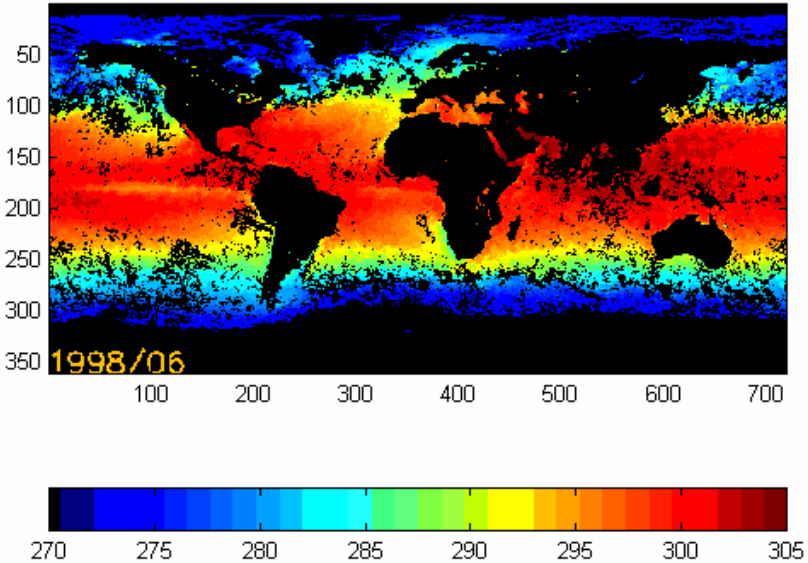
- **Hypothesis 3**: Microplastics will serve as a 3rd/4th/5th phase (DOC, BC), stabilizing POPs in the water column, reducing their sinks

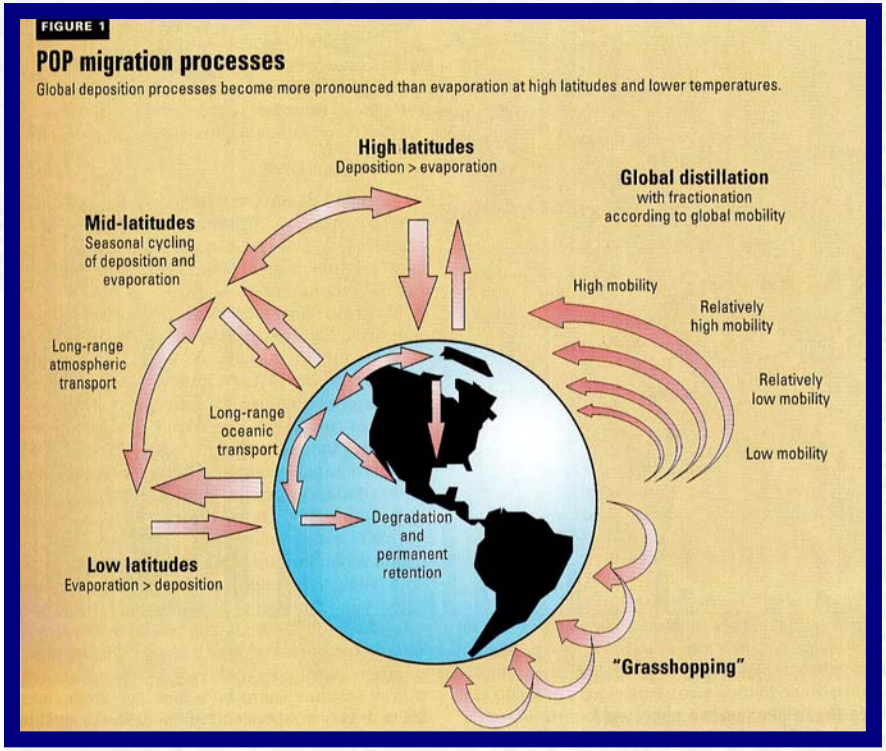
POPs

Poles are colder…



(Iwata *et al*., 1993, ES&T;
Simonich & Hites, 95, Science)



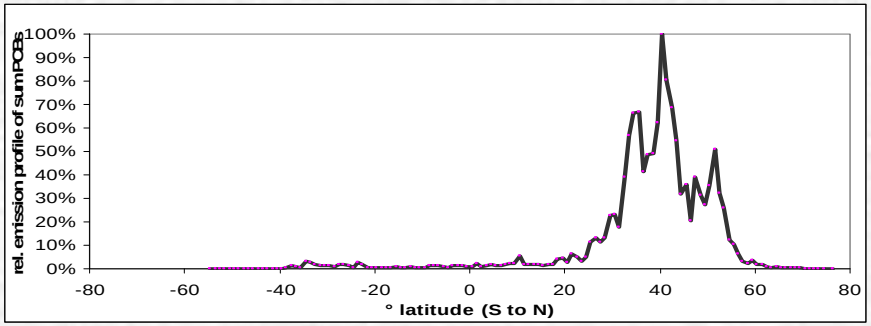


(Wania, F. and Mackay, D. , *Environ. Sci. Technol*. 30, 390A-396A, 1996)

Global fate = cold condensation?

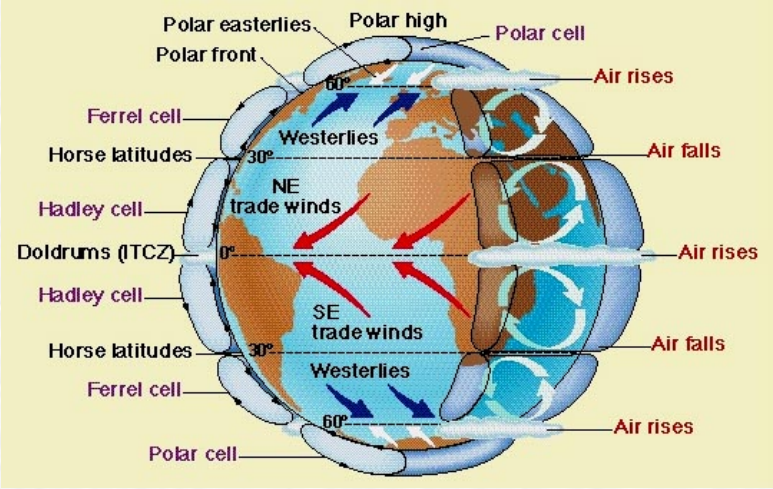
POPs

PCB historical use pattern



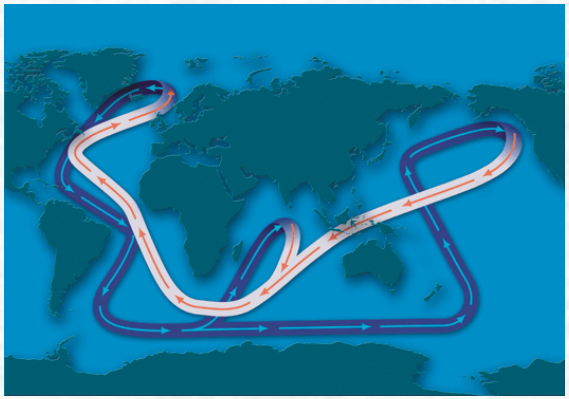
(Breivik et al., 2002a,b)

Atmospheric circulation



http://www.oceansonline.com/winds.htm

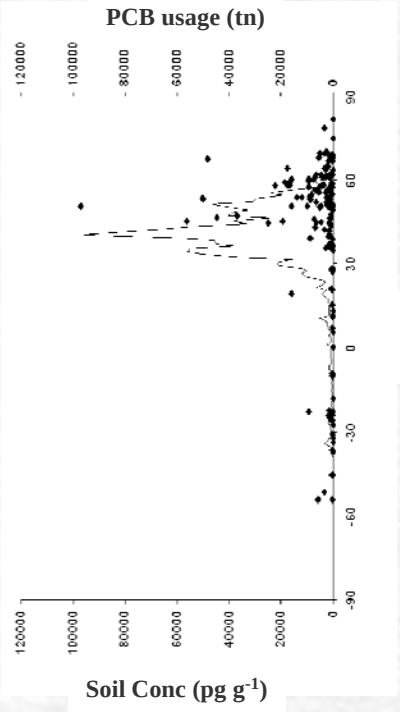
Water cycles, e.g. The ocean conveyor belt

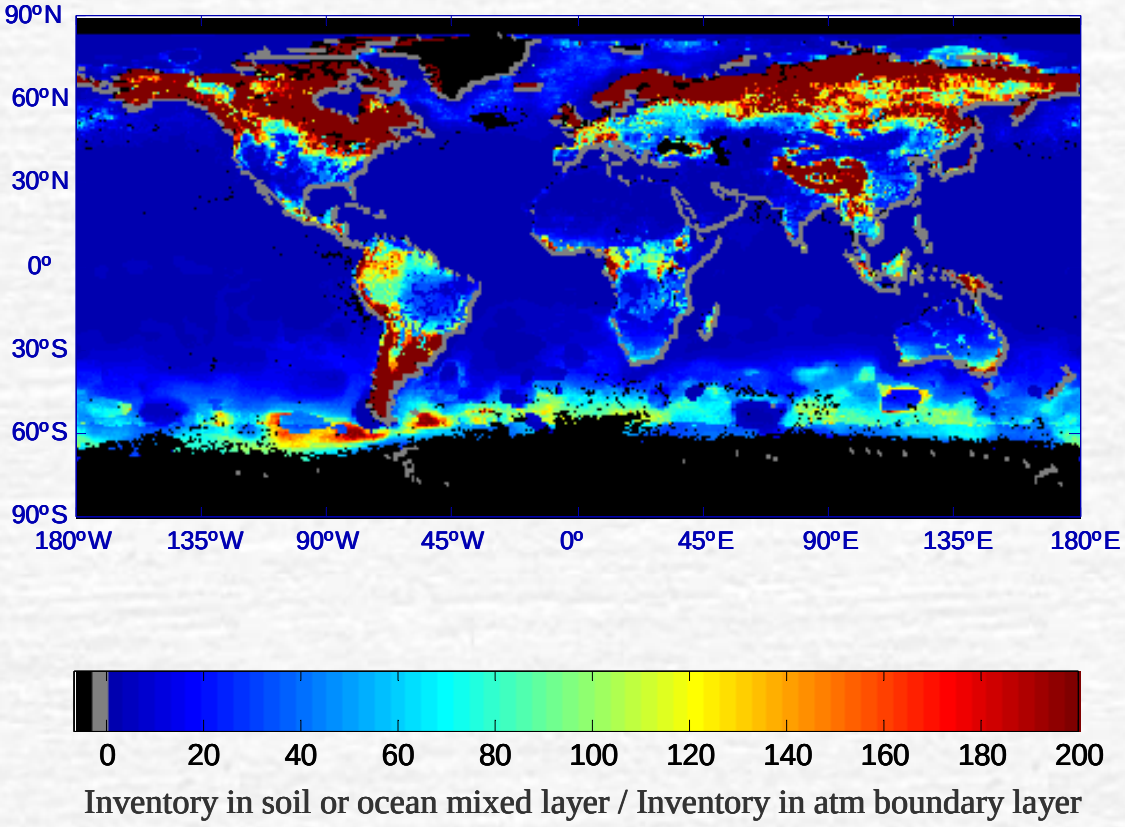


(Illustration by Jayne Doucette, WHOI Graphic Services)

maximum reservoir capacity in top soils and surface mixed layer vs. atmosphere

POPs



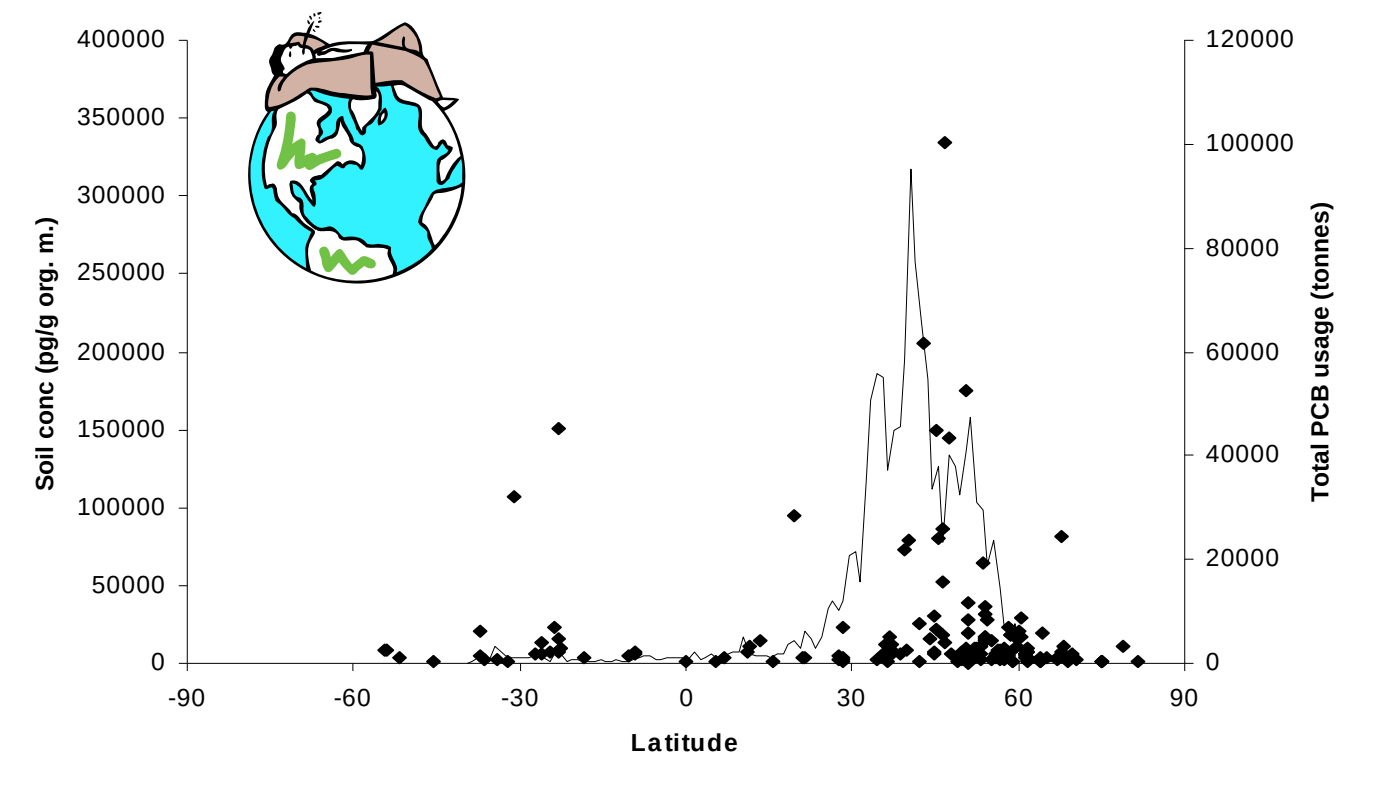


(from Dalla Valle et al. 2005).

POPs

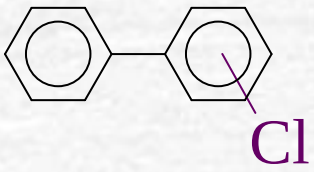
Global PCB usage: 650,000,000,000 kg

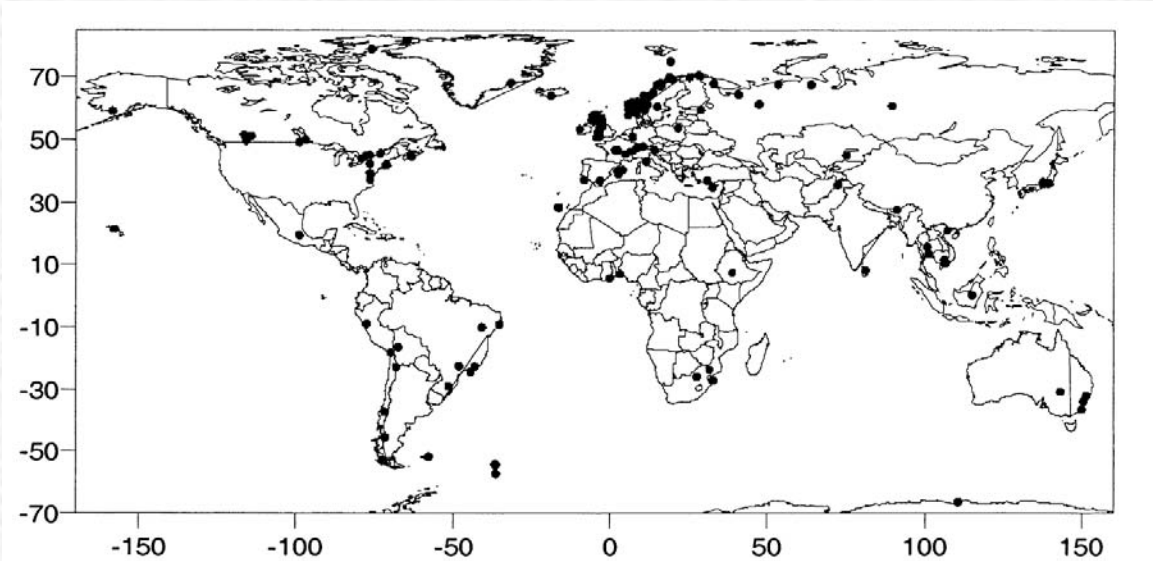
- soil samples from all over the world..



POPs

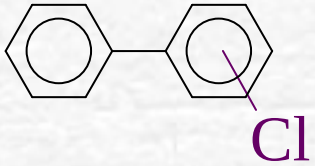
PCBs - global distribution - soil





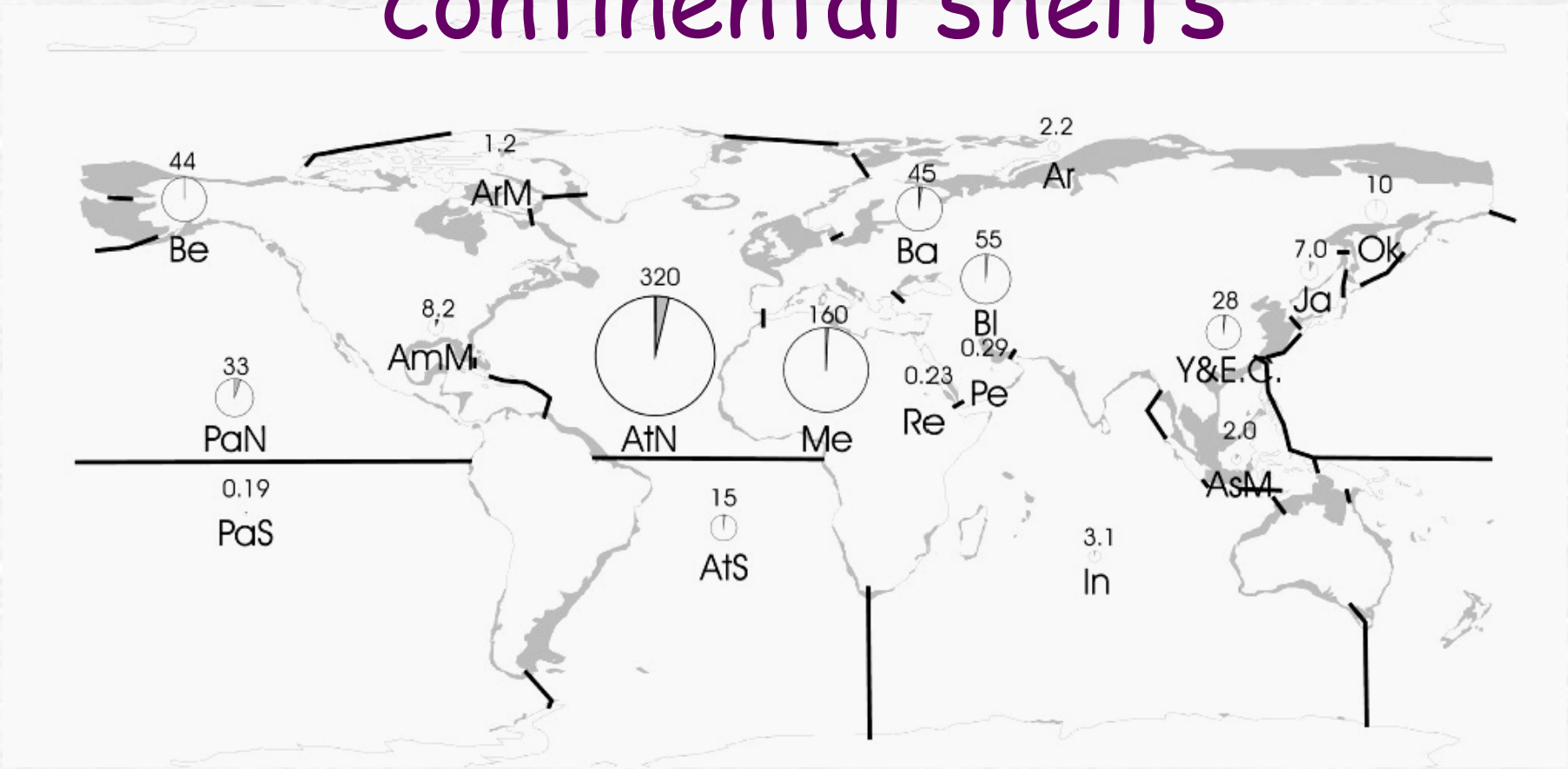
- Of maximum global emission are ca.
  - 5% of PCBs 28, 52
  - 30 - 50% of PCBs 153, 180 in soils
- > 60% inbetween 30 – 60 °N
- ca. 6% of total global production

(Meijer et al., *Environ Sci Technol*, 2003)

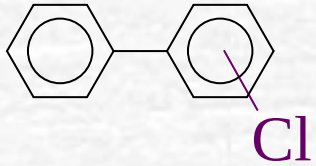


POPs

PCB 180 -mass balance in continental shelfs



(Jönsson et al., *Environ Sci Technol*, 2003)



POPs

PCBs in continental shelf sediments

- > 50% in the North Atlantic
- of maximum global emission
  - ~ 10% PCBs 28, 52
  - ~ 80% PCBs 153, 180

  in continental shelf sediments

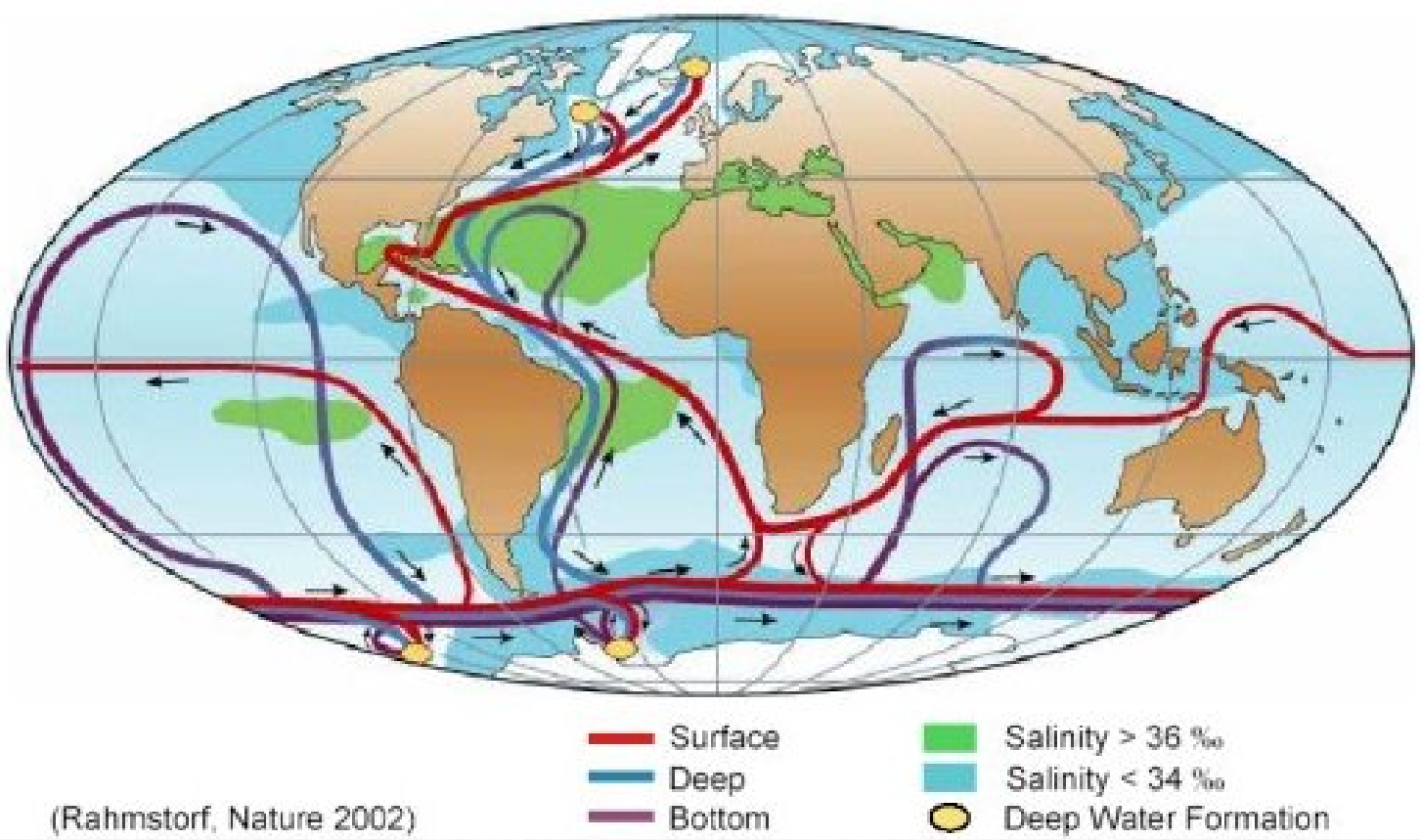
ca. 1-6% of the total global production!

(Jönsson et al., *Environ Sci Technol*, 2003)

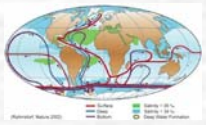
Global fate of POPs

- Complex interplay..
- **At least 10% of PCBs produced are out** (shelf sediments and soils)
- Mostly retained in NH
- Cold condensation only 60 – 90 N
- Atmospheric losses?
- Current emissions?
- Role of microplastics?

'Physical pump' of POPs: Deep water formation



Lohmann, Jurado, Pilson, Dachs, GRL 2006

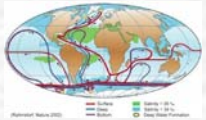


considered subduction regions

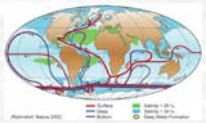
Region	Zone	Flux (Sv)
Norwegian Sea	68N – 80N, 0 – 25 E	15
Labrador Sea	50N – 60N, 40W – 60 W	12
Weddell Sea	60S – 85S, 70W – 20 W	10
Ross Sea	69S - 76S, 155W – 160E	11
from Ganachaud and Wunsch, 2000		(1 Sv = 10^6 m^3/s)

Lohmann et al., *Geophys Res Letter*, 2006

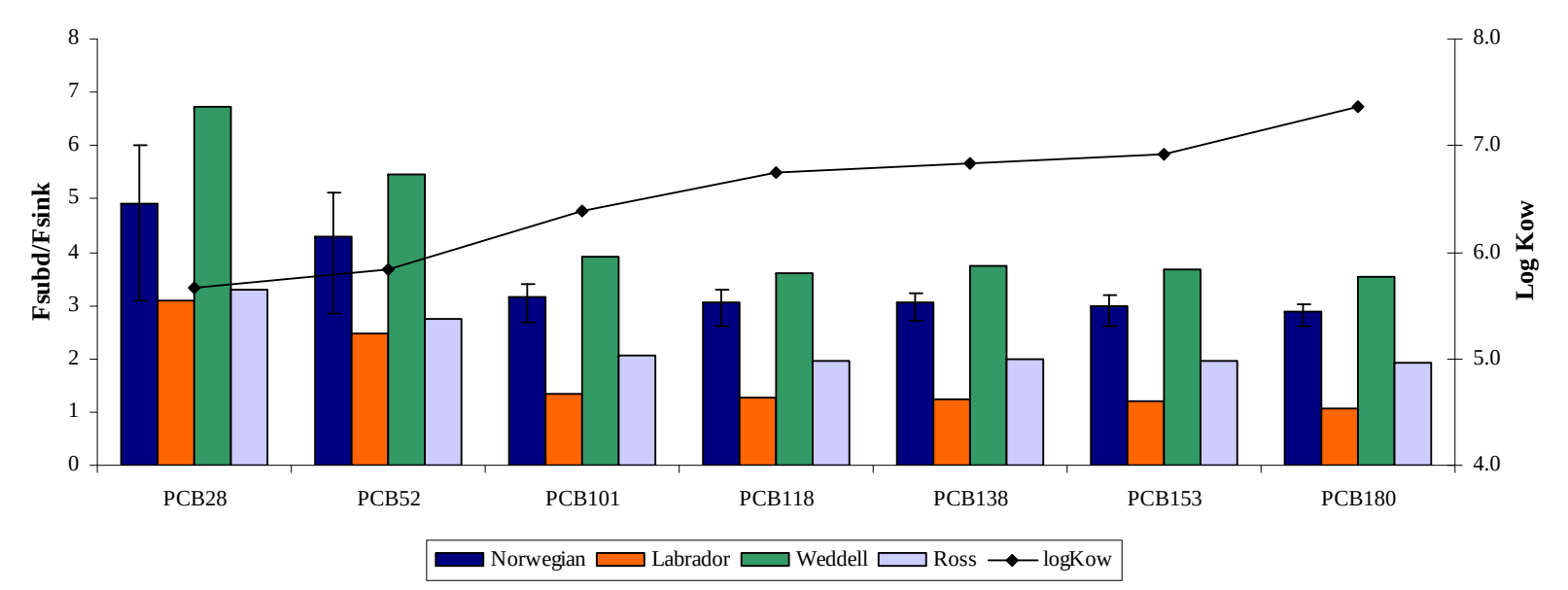
PCB removal fluxes (kg/yr) $F_{subduction}$ vs. F_{sink}

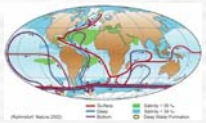


Region	flux	Sum PCBs
Norwegian Sea	F_{sub}	420
Labrador Sea	F_{sub}	140
Weddell Sea	F_{sub}	160
Ross Sea	F_{sub}	150
Sum 4 regions	F_{sub}	870
Sum 4 regions	F_{sink}	320
Total Atlantic	F_{sink}	22,000



Ratio of PCB profiles in subduction *vs* carbon settling flux

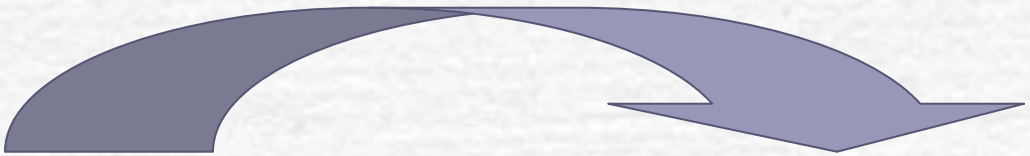




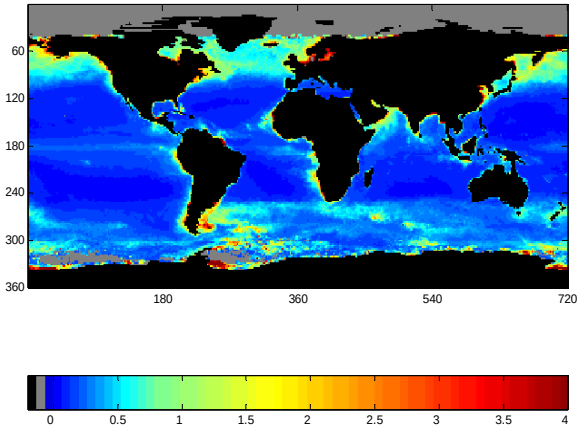
Implications & possibilities

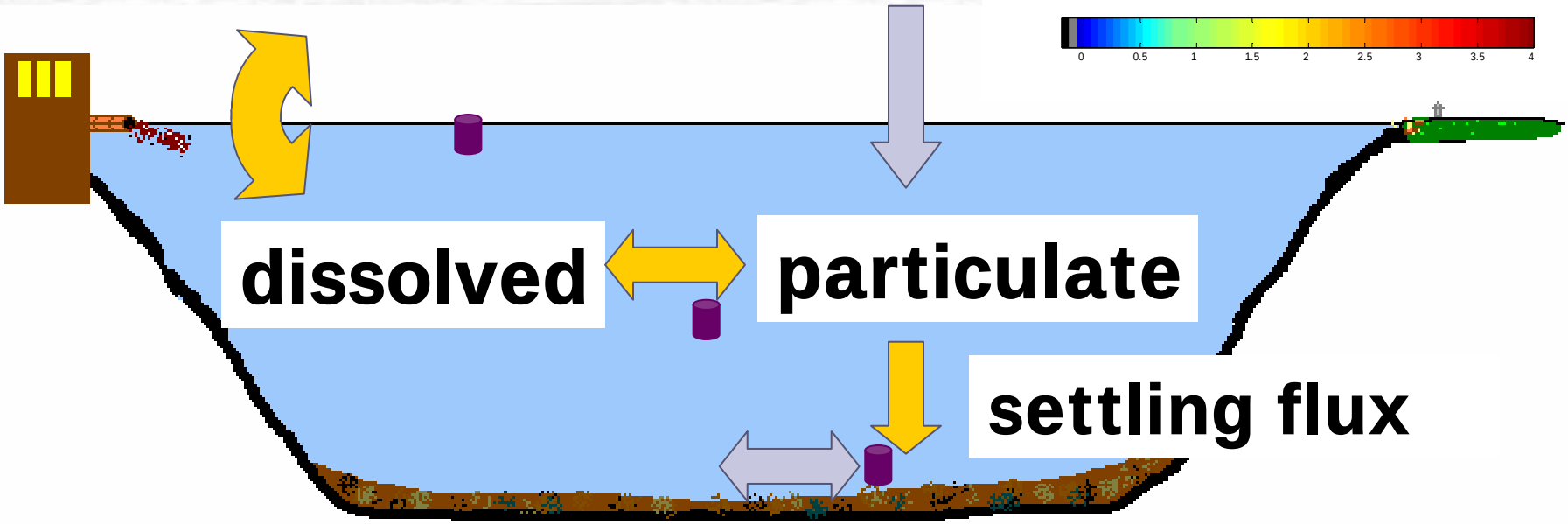
- POPs as water mass 'tags' …. (read: PFOs…)
- Different signatures for surface and deep water masses
- Deep ocean water can be traced for last few decades
- Changes in chemical composition indicate biological processes
- But, also transport of POPs to depth via particles and diffusion…
- **Transport of microplastics to the deep!**

Biological pump



gaseous ⟷ **bound**





microplastics

PAHs along the Atlantic Ocean

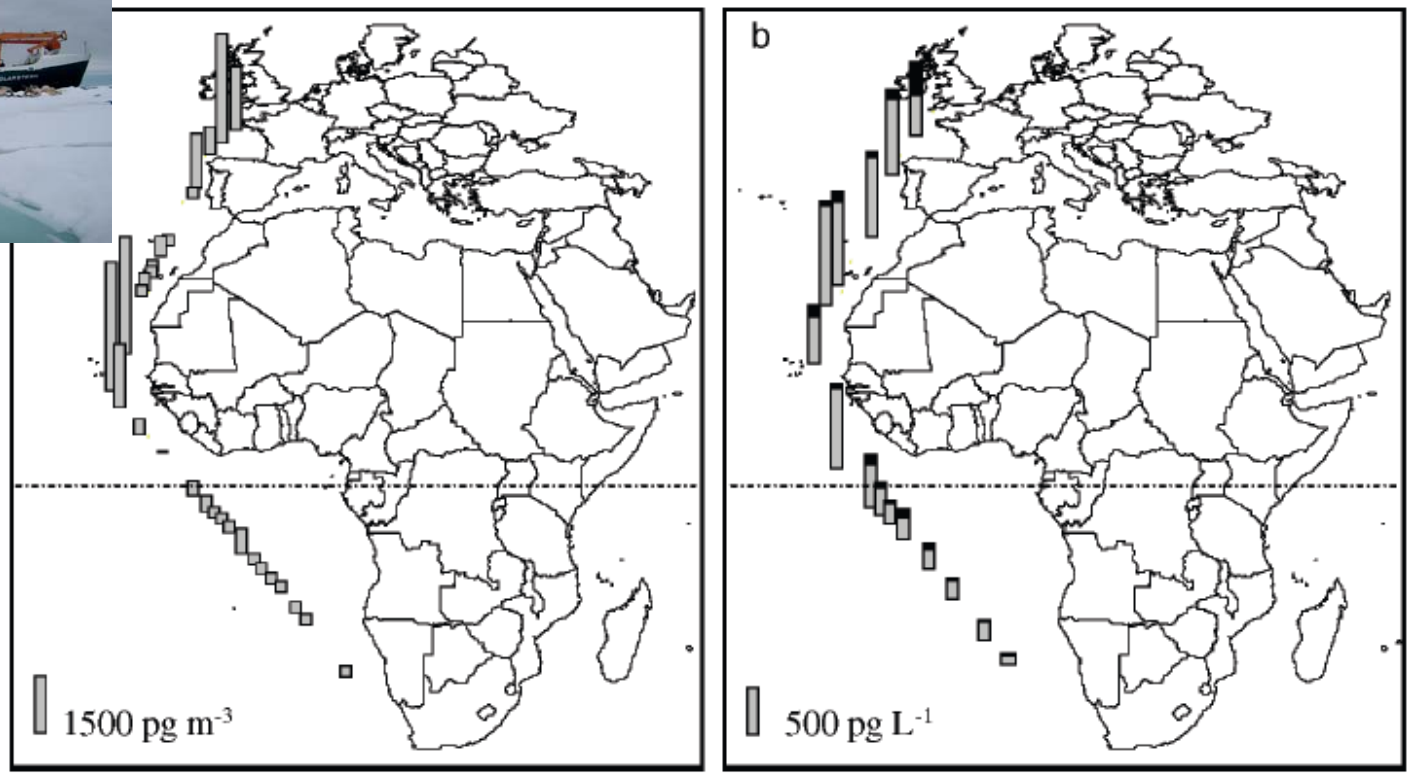


FIGURE 1. Latitudinal distribution of Σ_{10} PAHs in (a) air, and (b) water (grey represents the dissolved fraction and black the particle associated fraction).

Nizzetto et al., EST 2008

PAHs in a/w not in equilibrium

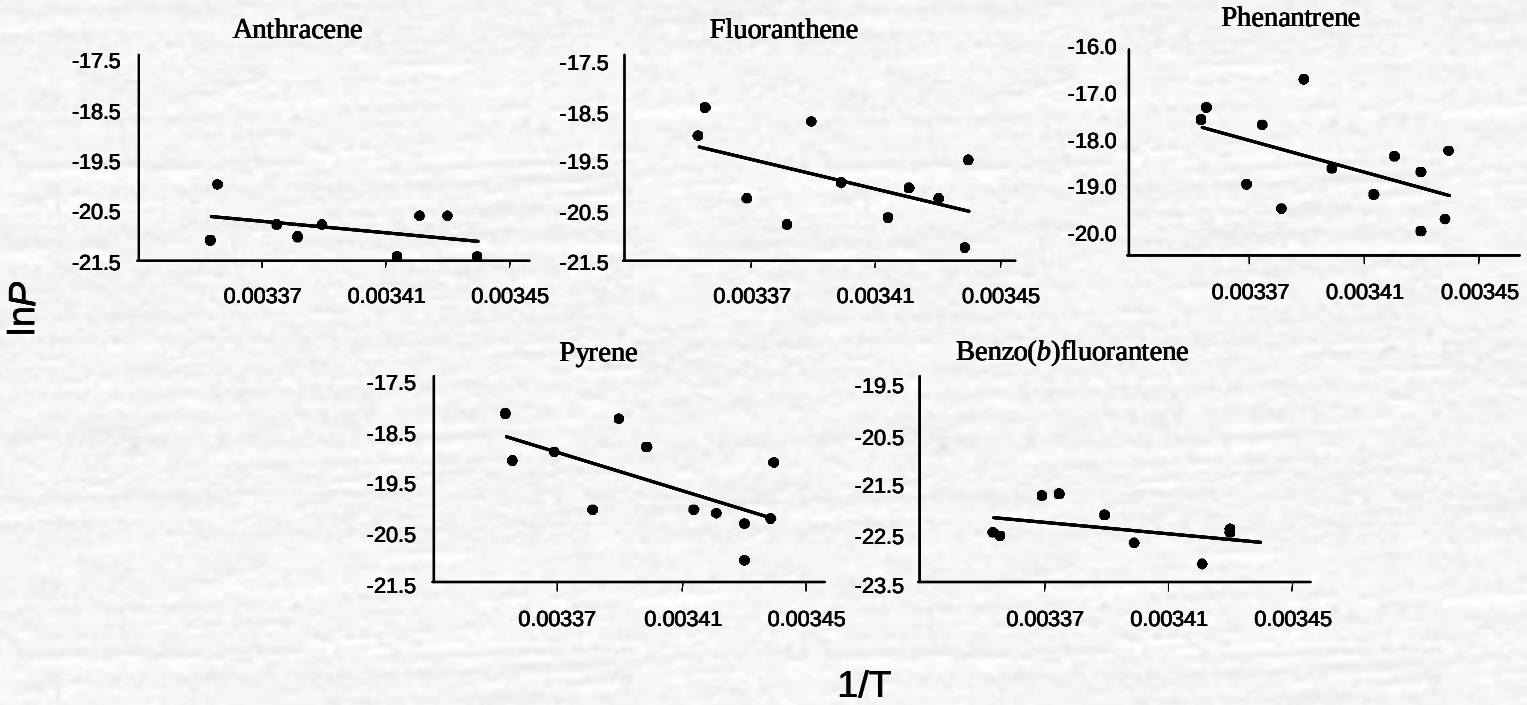


Figure SI_1 ln*P* vs 1/T plots for SH

Where are the PAHs from?

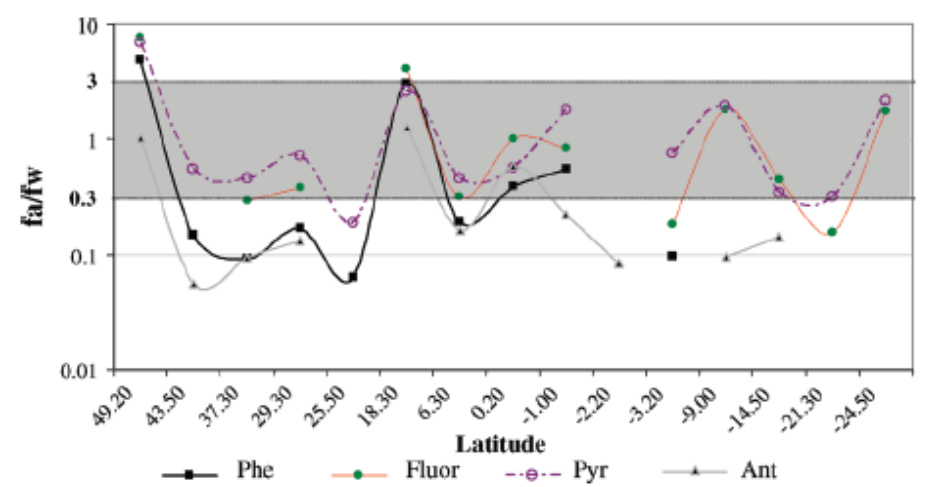


FIGURE 3. Fugacity ratios of selected PAHs. The grey area shows the uncertainty of air–water equilibrium; ratios outside suggest PAHs not at air–water equilibrium.

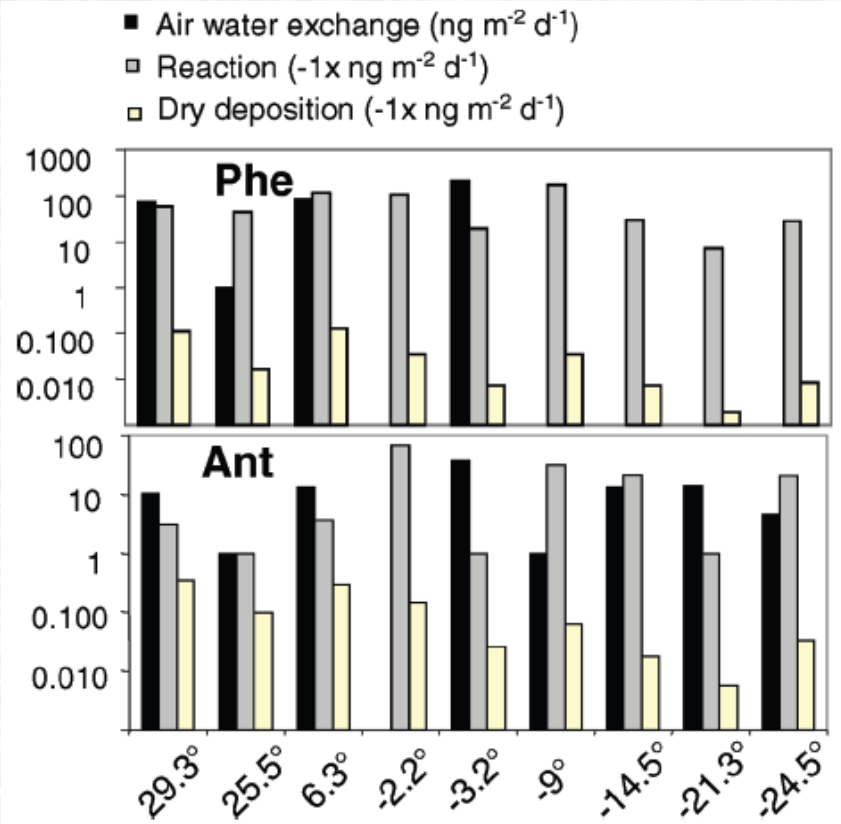
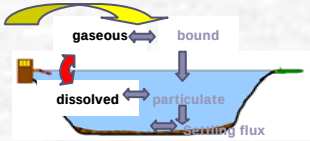


FIGURE 4. Calculated intercompartmental fluxes of phenanthrene and anthracene in areas with $f_a/f_w < 0.3$.

Natural sources?

Nizzetto et al., EST 2008

Atlantic Σ_7PCBs



(Jaward et al., *Environ Sci Technol*, 2004)

PCBs?

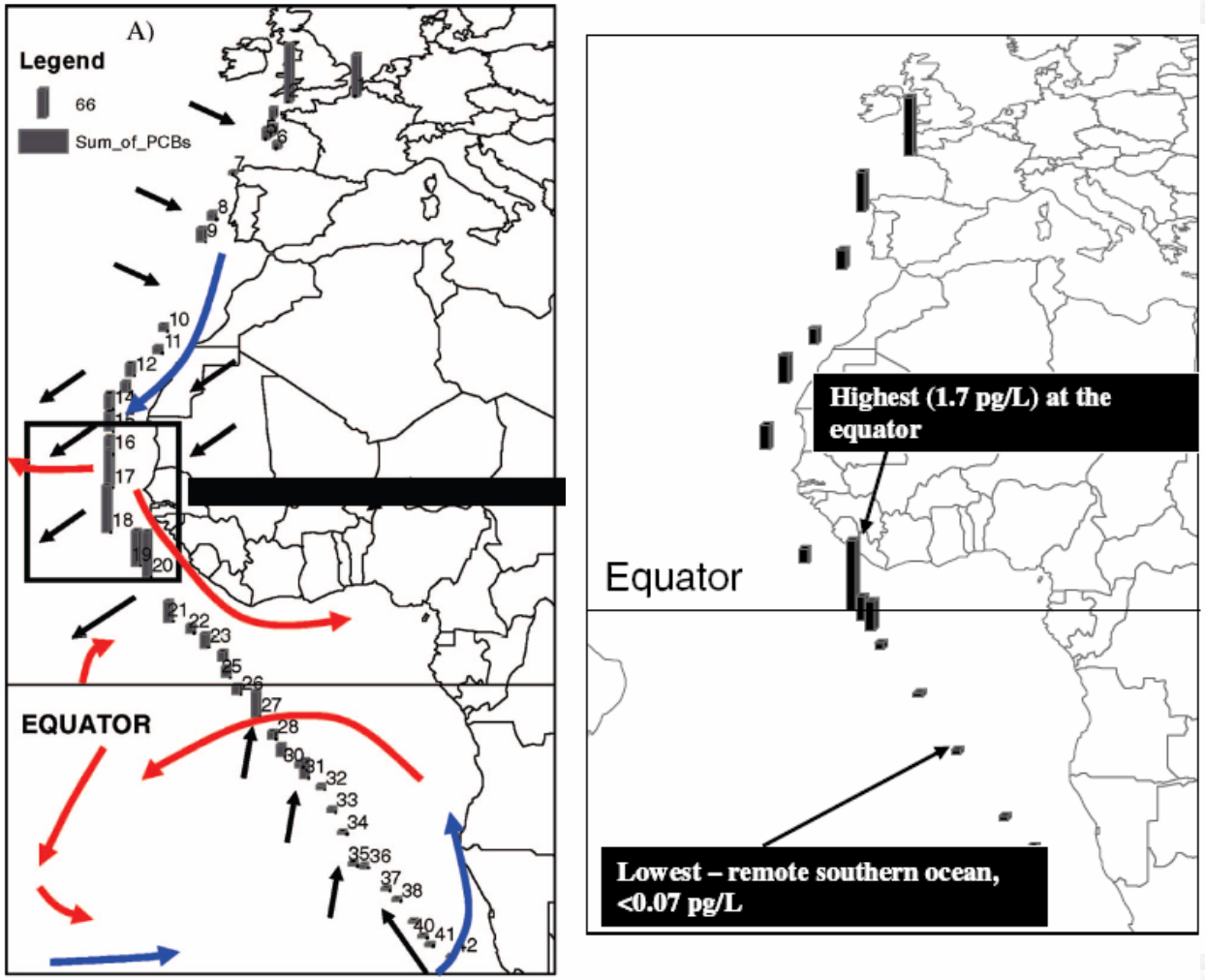
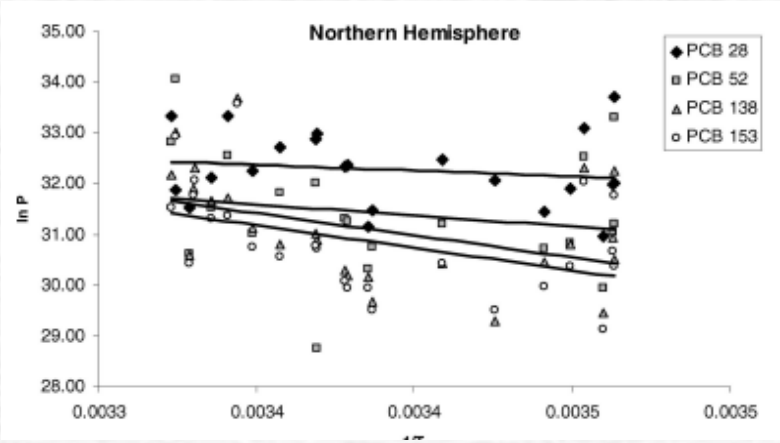


FIGURE 1. Black arrows represent broad origin of the air masses during the cruise on board the *RV Polarstern*. The blue arrows represent cool sea surface currents, while the red arrows represent warm sea surface currents. Number 1–43 are the site locations. Black bars indicate concentrations of Σ_{ICES} PCBs in air along the cruise (n = 43). Note: the bars centre on the average sample location. Key: largest bar = 220 pg m^{-3} (site 18); smallest bar = 3.7 pg m^{-3} (site 43). B) Detailed figure of the West African coast, showing the PCB congener profiles for the high samples and 72 h back trajectories for each sample.

Gioia et al., EST 2008

Time-trends?

- No significant change in air or water from 1990 (Schreitmueller and Ballschmiter) to 2005 (Gioia et al., 2008)
- N-Atlantic: emissions; SH: a/w equilibrium



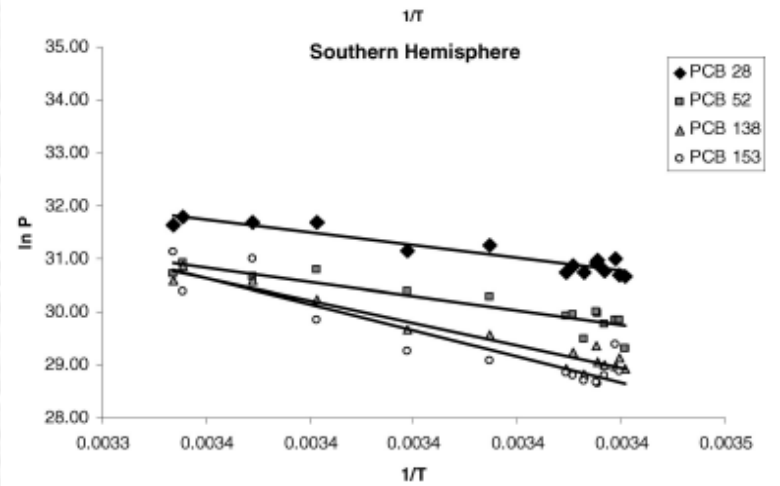
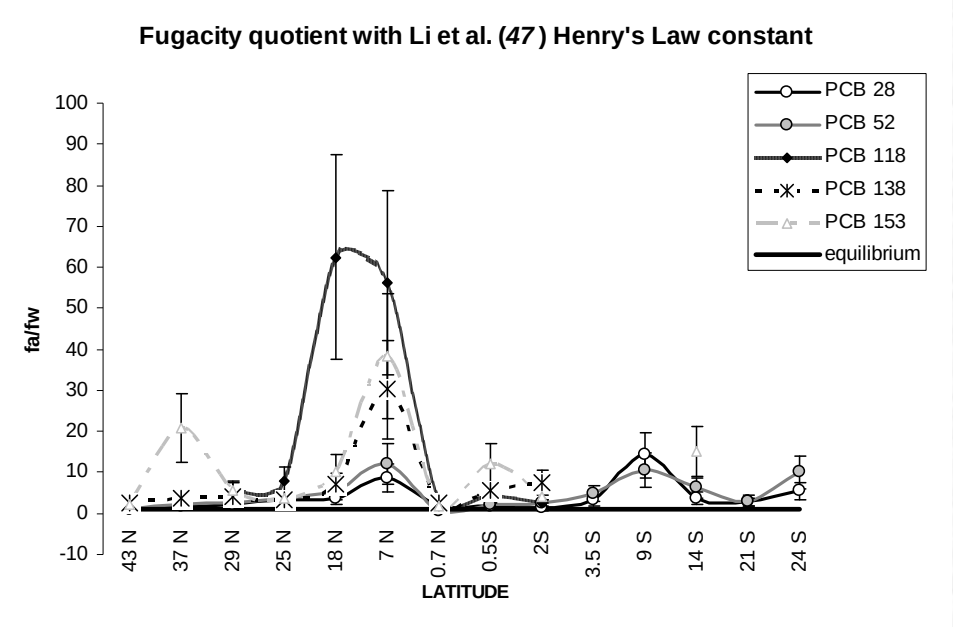
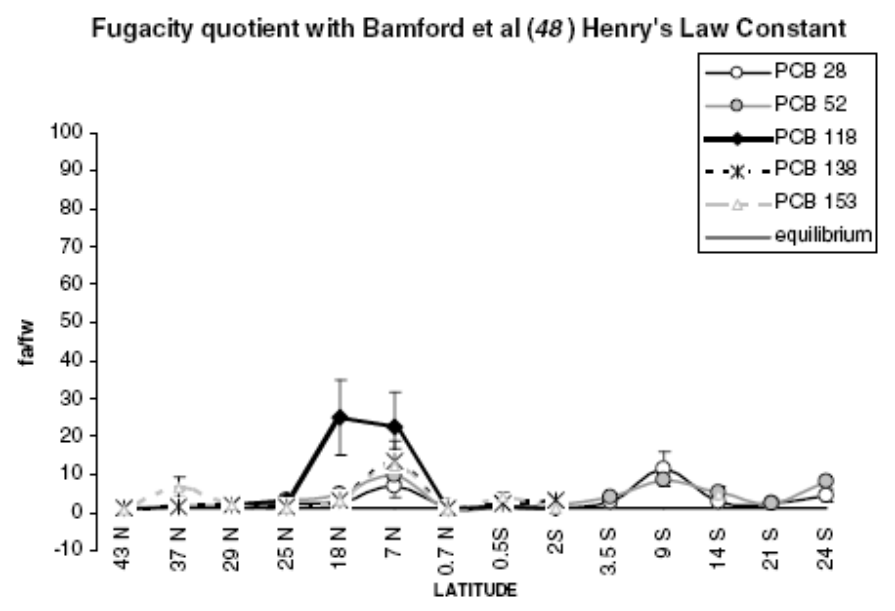


FIGURE 2. lnP versus 1/T plot for selected PCB congeners in the north and south hemisphere.

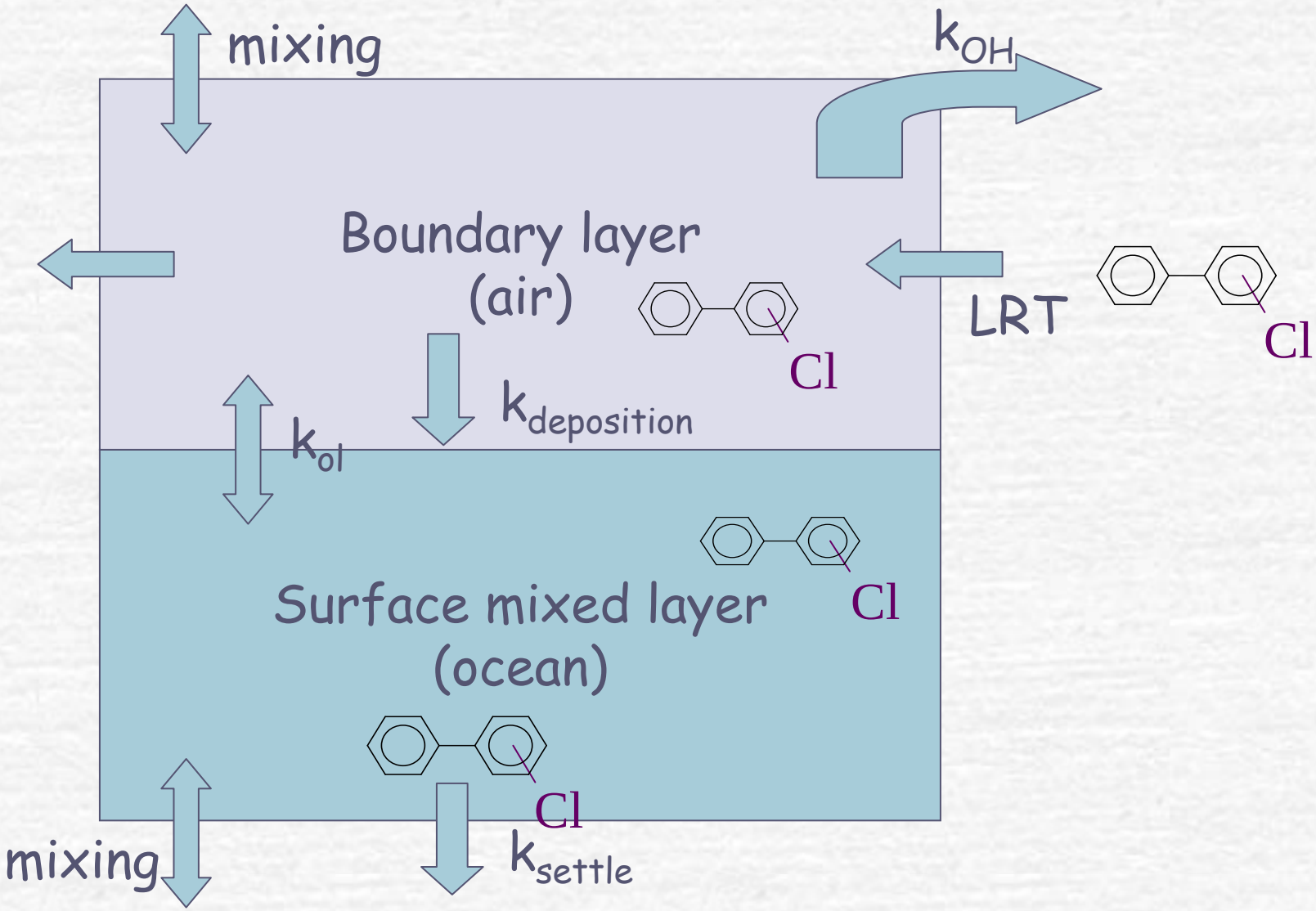
PCB flux mostly from air-to-water



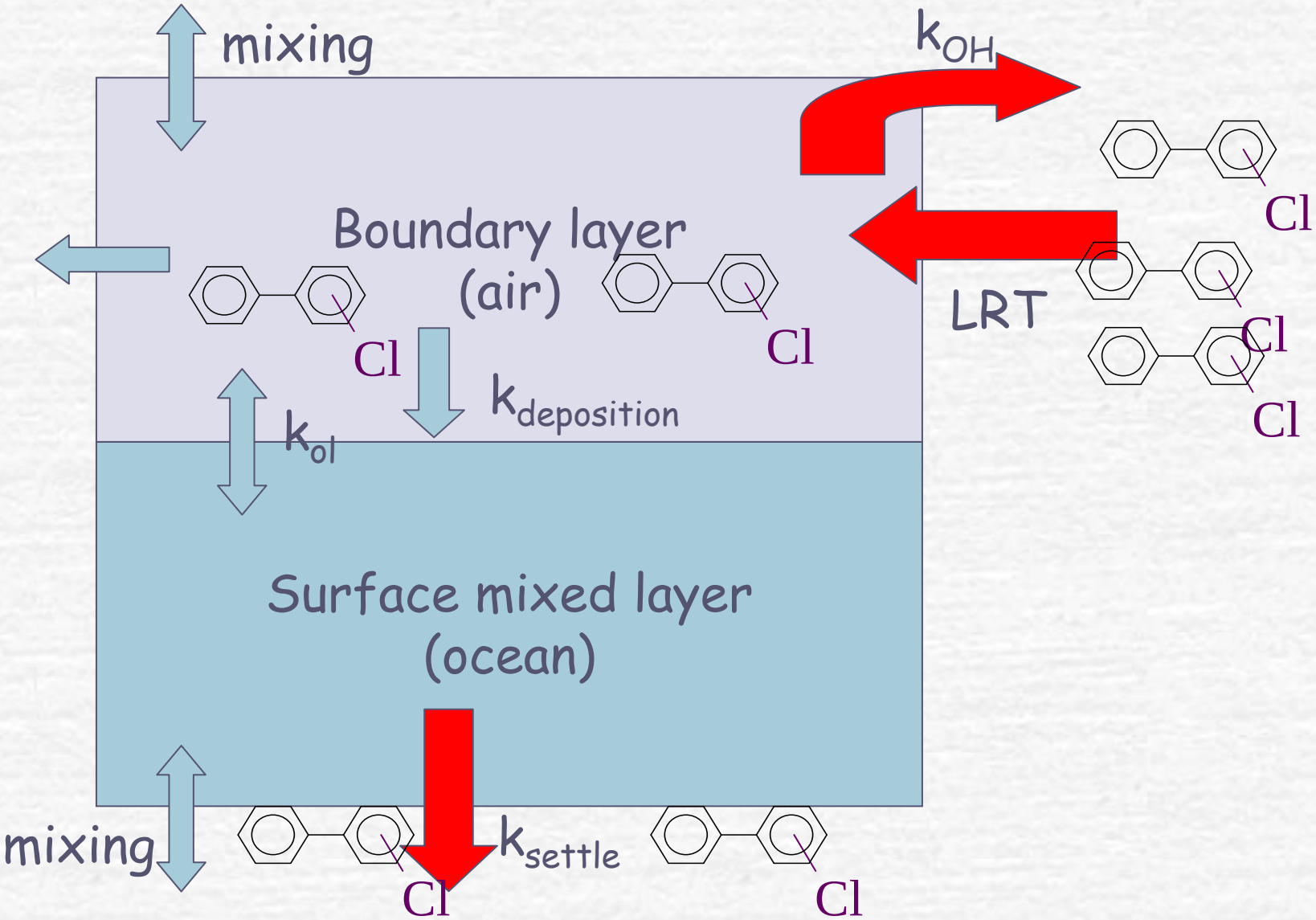


Gioia et al., EST 2008

A simple model



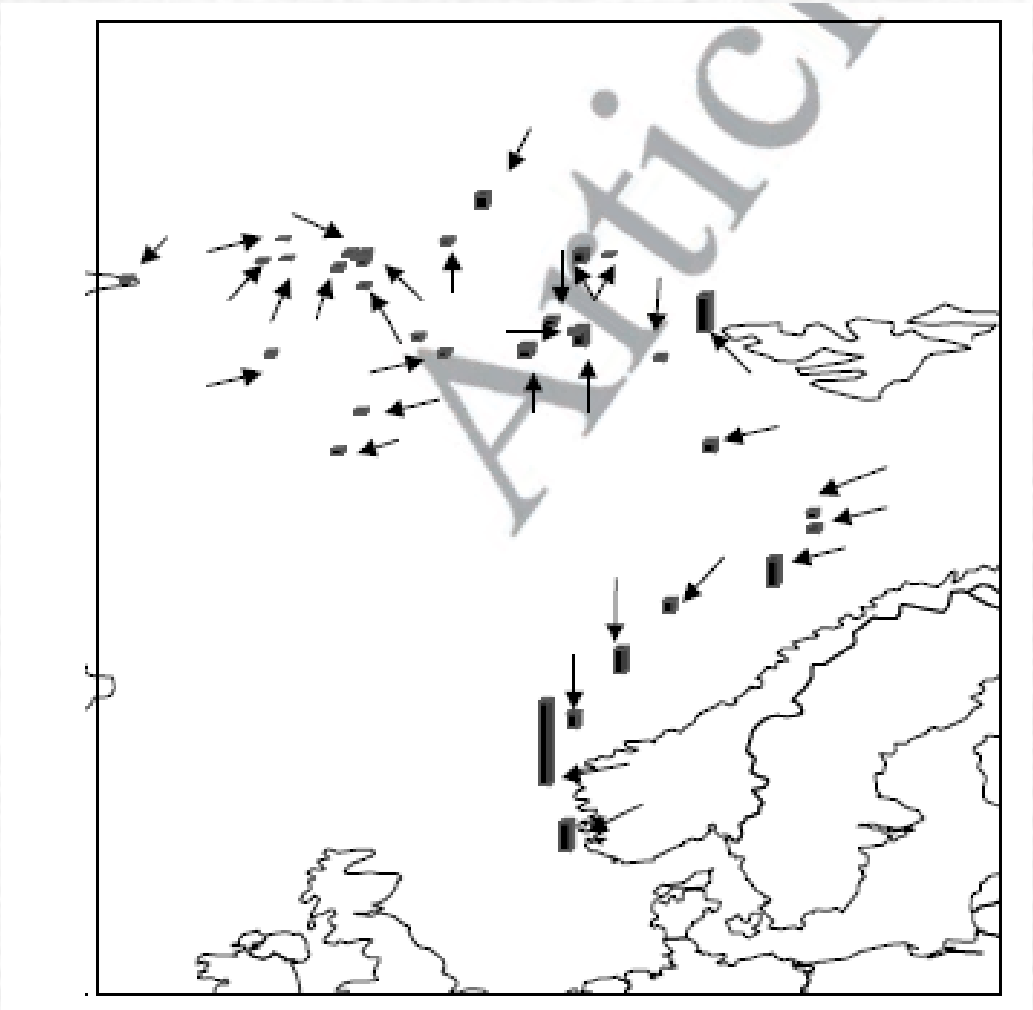
For Atlantic cruises



Some conclusions

- Strong emission peaks of NW Africa
- In N-Atlantic dominated by emissions
- In S-Atlantic PCBs close to air-water equilibrium; PAHs not
- Exception for PAHs… dioxins
- Role of Microplastics in cycling of POPs – maybe in SH, PAHs

PCBs in Arctic



Frationation in air and water observed

Air-water exchange of PCBs

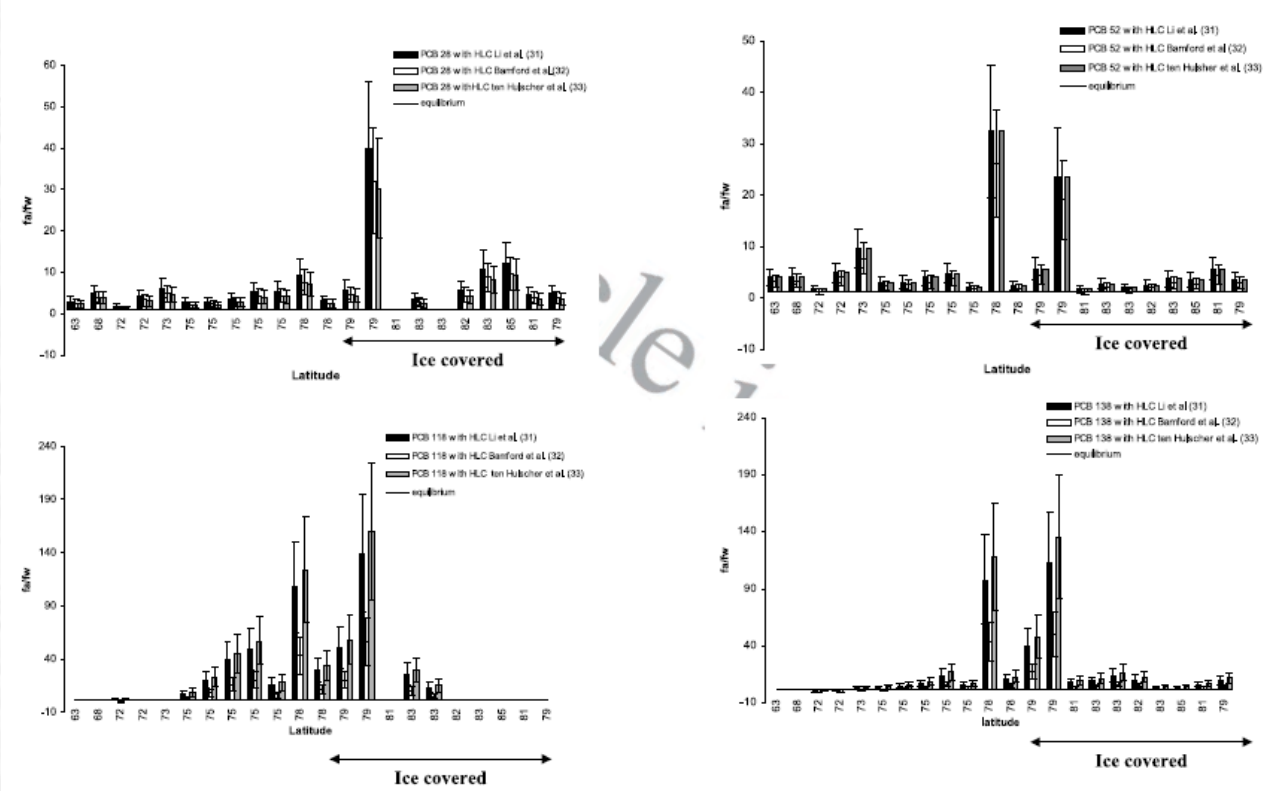


Figure 4. Fugacity fractions of four PCB congeners (28, 52, 118, and 1380 versus latitude. Henry's Law constants were taken from *Bamford et al.* [2002], *Li et al.* [2003], and *ten Hulsher et al.* [2006].

Gioia et al., JGR-Atmosphere, in press

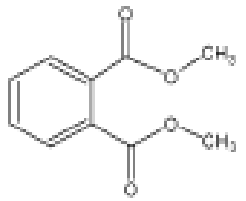
Phthalates in the Arctic

Occurrence and Air—Sea Exchange of Phthalates in the Arctic

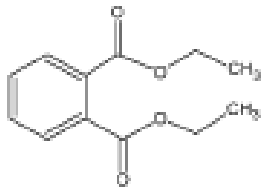
ZHIYONG XIE,[†,‡] RALF EBINGHAUS
CHRISTIAN TEMME,[†]
RAINER LOHMANN,[*,§]
ARMANDO CABA,[†] AND
WOLFGANG RUCK[‡]

TABLE 1. Summary of Results of Dissolved Phthalates in the Arctic[a]

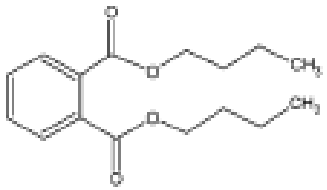
phthalate	MDL (pg L^{-1})	detectable frequency (%)	mean (pg L^{-1})	median (pg L^{-1})	minimum (pg L^{-1})	maximum (pg L^{-1})
DMP	13	42	40	13	<13	312
DEP	8	71	138	40	<8	795
DiBP	5	65	22	6	<5	204
DnBP	3	100	51	29	8	349
BBP	0.2	95	8	6	<0.2	48
DEHP	24	88	448	221	<24	3330
Σ_6 phthalates			705	359	80	5030



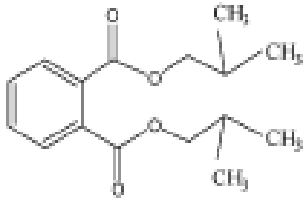
Dimethyl phthalate (DMP)



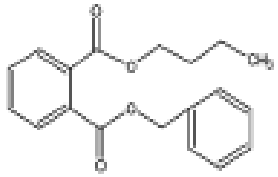
Diethyl phthalate (DEP)



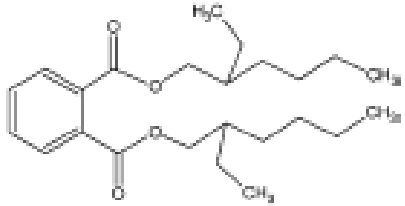
Dibutyl phthalate (DnBP)



Diisobutyl phthalate (DiBP)



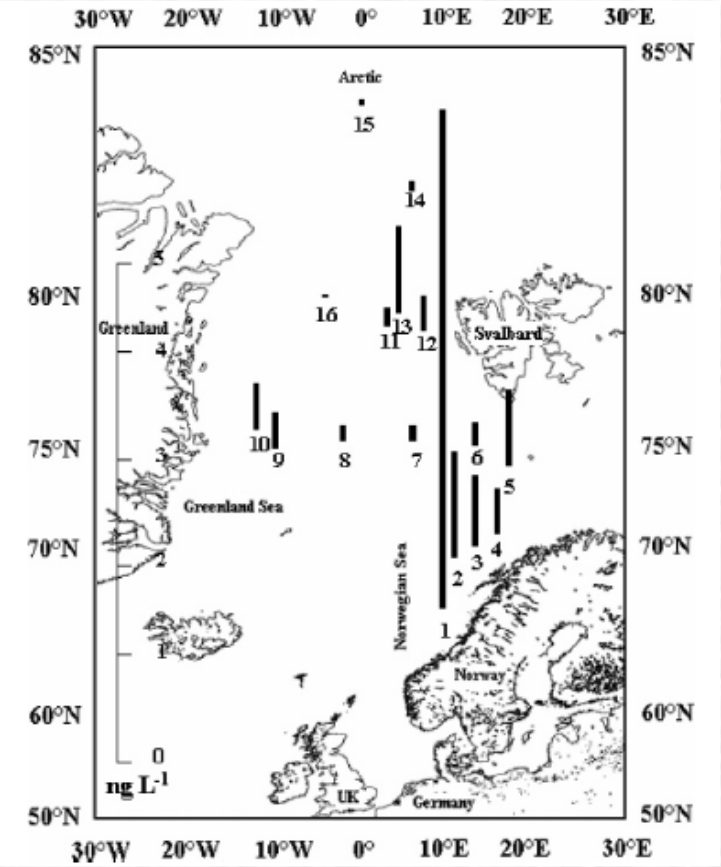
Benzylbutyl phthalate (BBP)

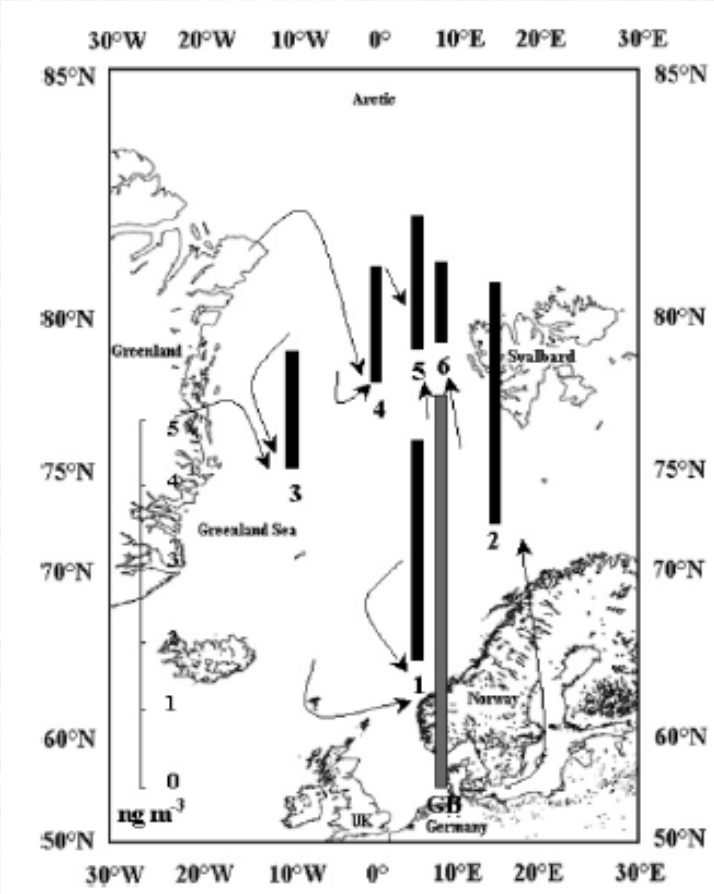


Diethylhexyl phthalate (DEHP)

Short-lived in air and water

Water - Air


30°W 20°W 10°W 0° 10°E 20°E 30°E
85°N
80°N
75°N
70°N
60°N
50°N
Arctic
Greenland
Greenland Sea
Norwegian Sea
Svalbard
Norway
UK
Germany
ng L-1


30°W 20°W 10°W 0° 10°E 20°E 30°E
85°N
80°N
75°N
70°N
60°N
50°N
Arctic
Greenland
Greenland Sea
Svalbard
Norway
UK
GB
Germany
ng m-3

Which way are phthalates moving?

- For DEHP, close to equilibrium
- For other phthalates, drastic air-to-water gradients

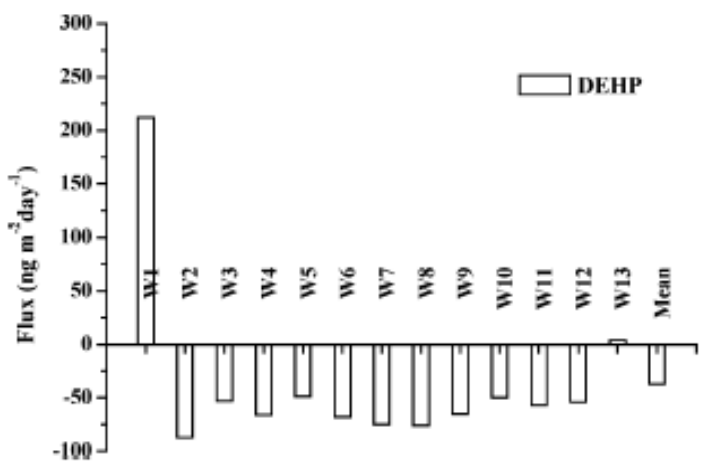


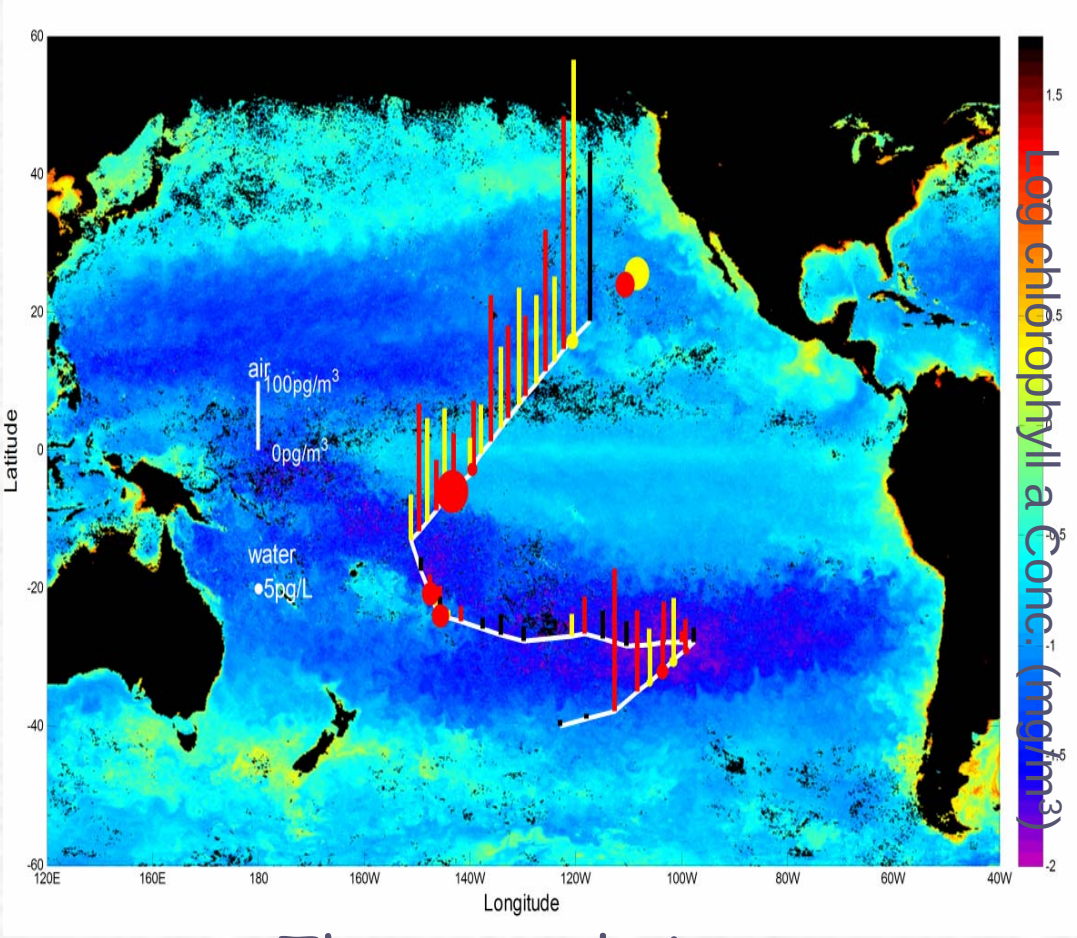
FIGURE 4. Air–sea gas exchange fluxes of DEHP in the Arctic (W14, W15, and W16 are excluded, as they were collected under sea ice).

Possibly due to

- (i) “dirty plume” in air
- (ii) fast destruction in water
- (iii) *H* values too low
- (iv) rapid loss from C_{diss}
- (v) contamination of air samples;
- And/or combination of these factors.

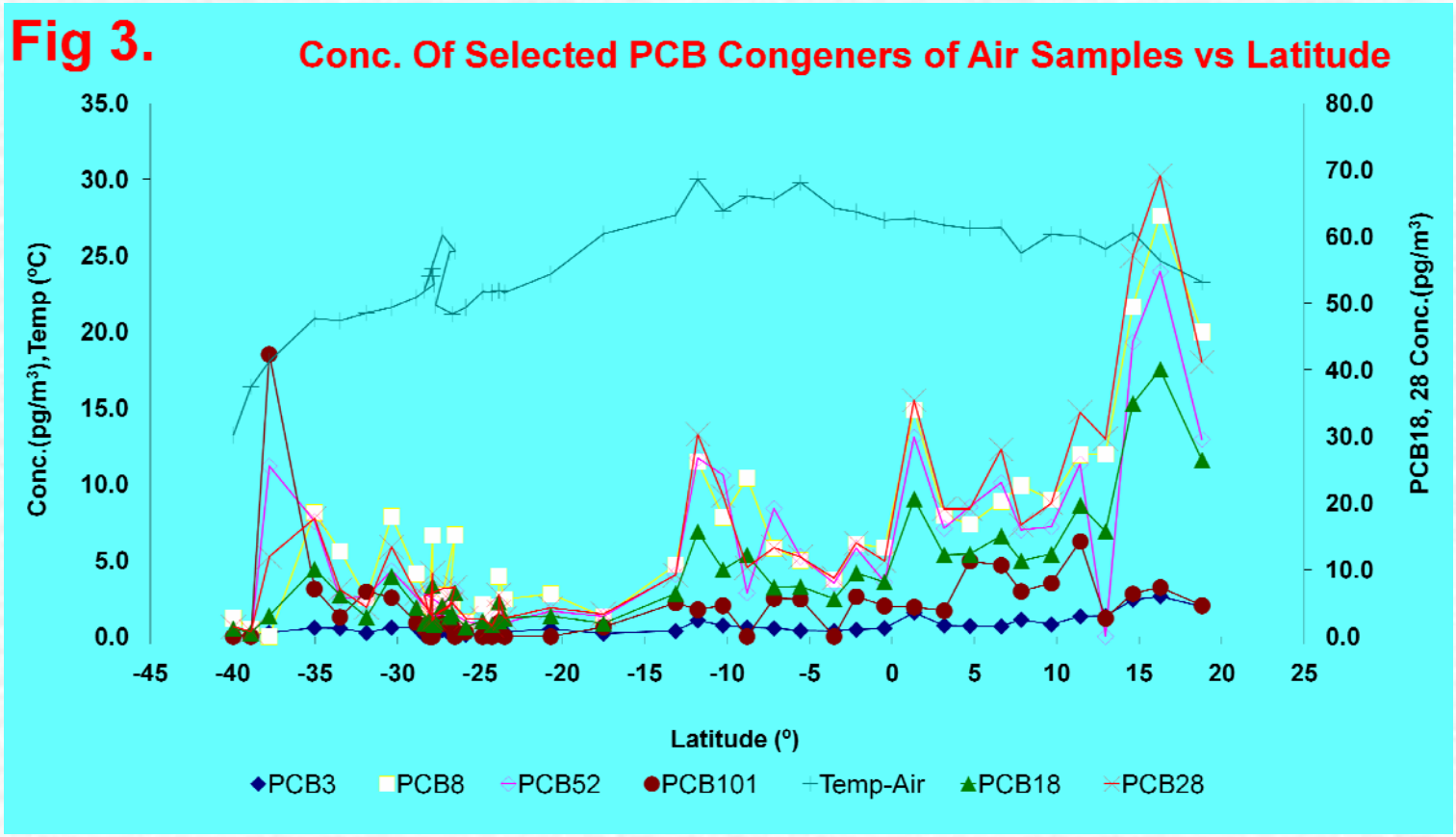
Zie et al., EST 2007

RV Revelle PCBs - Pacific'07



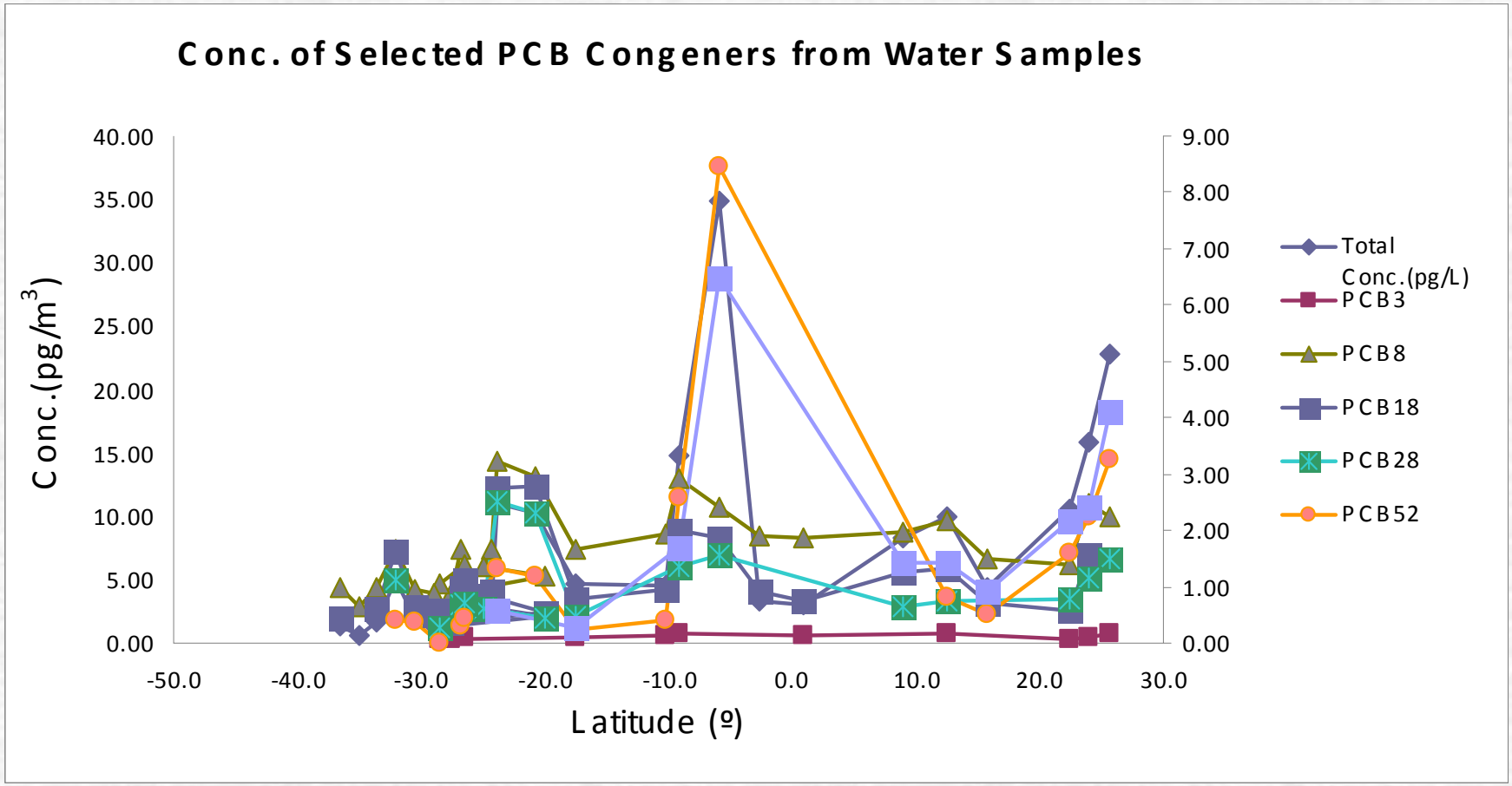
Zhang et al., in prep

PCBs in the marine boundary layer

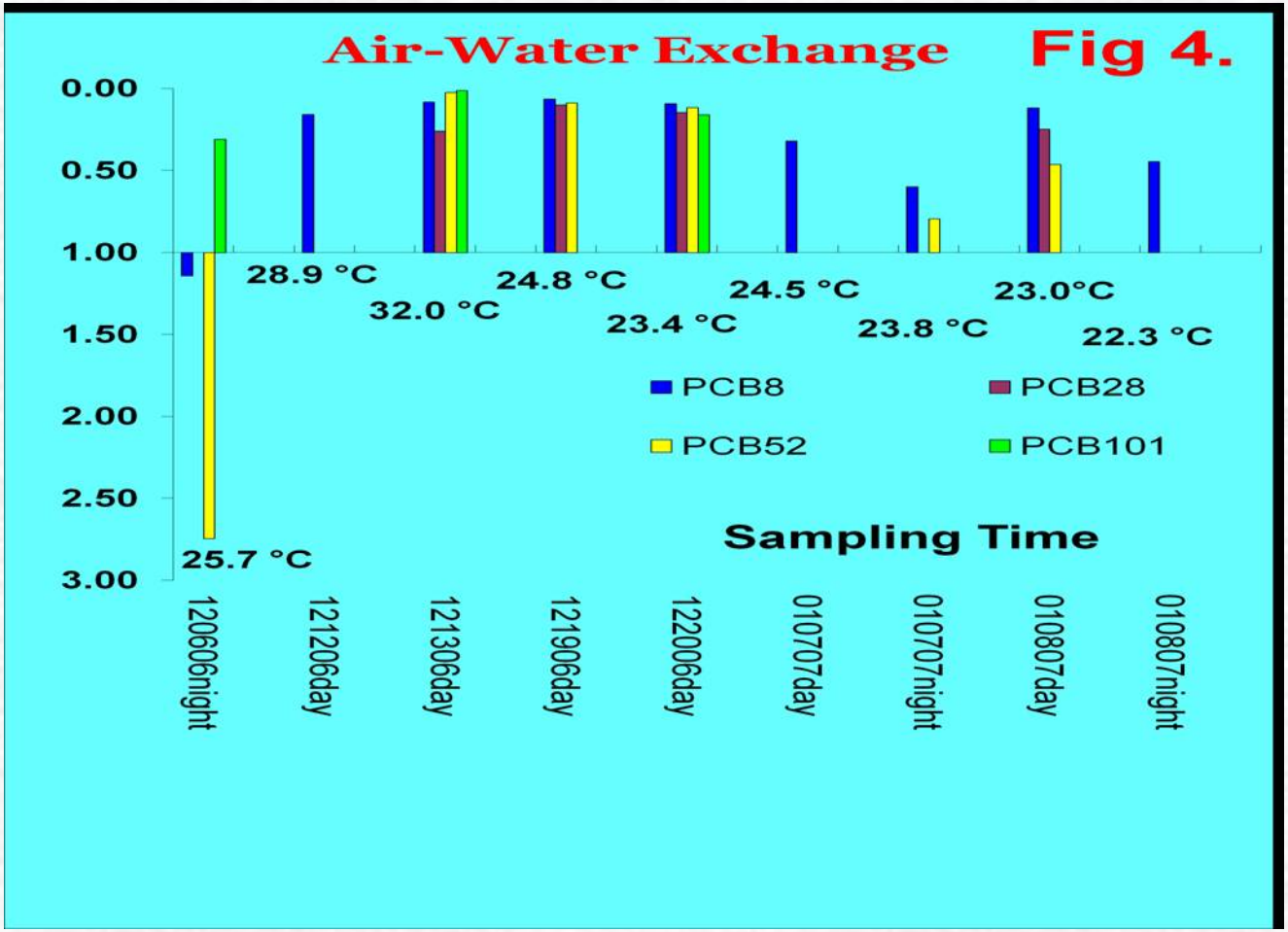


Ruß
gasförmig
gebunden (OC)
gelöst
gebunden
Ruß
Sinkstoffrate

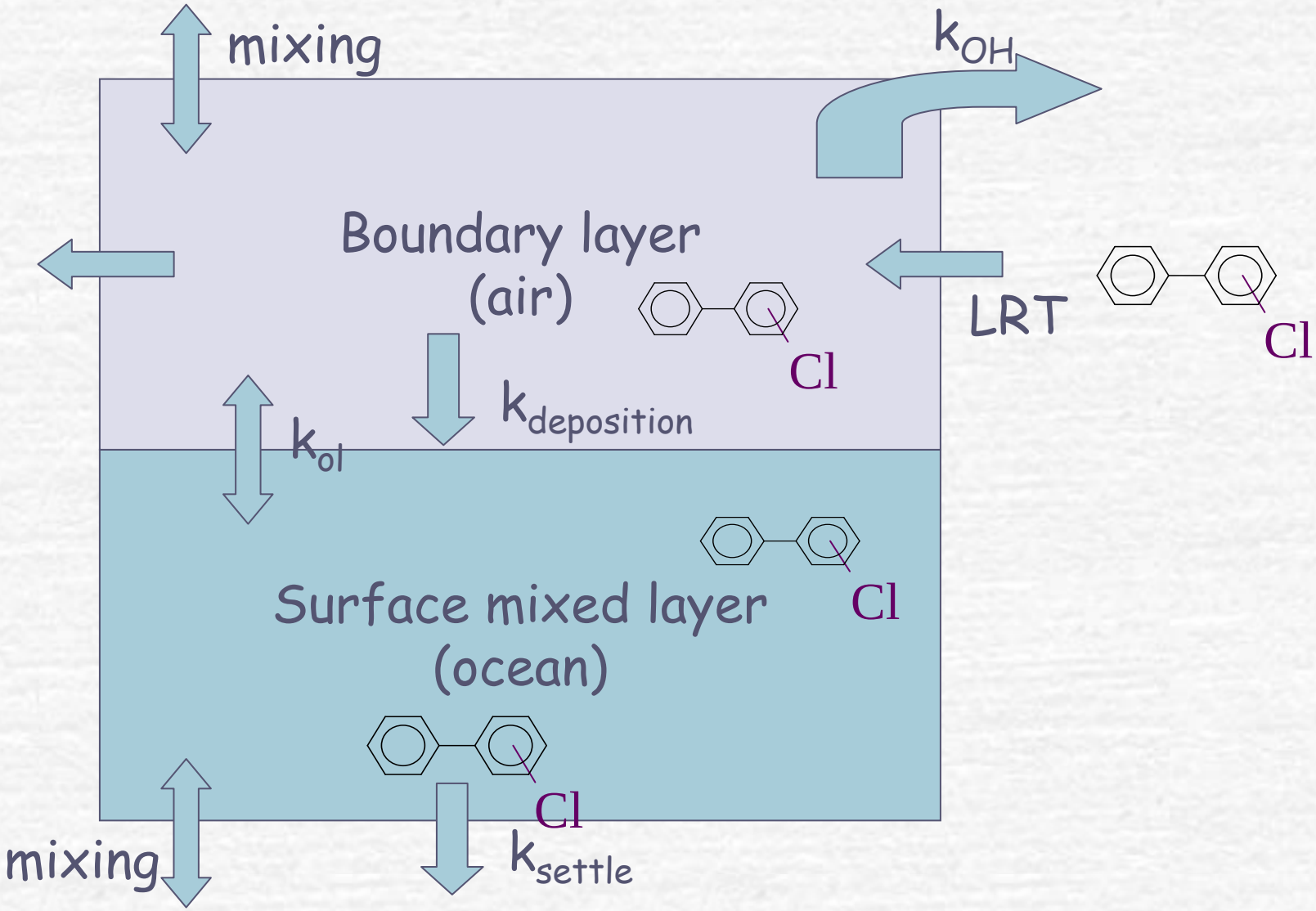
‘wet’ PCBs


Conc. of Selected PCB Congeners from Water Samples
Conc.(pg/m3)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
Latitude (º)
Total Conc.(pg/L)
PCB3
PCB8
PCB18
PCB28
PCB52

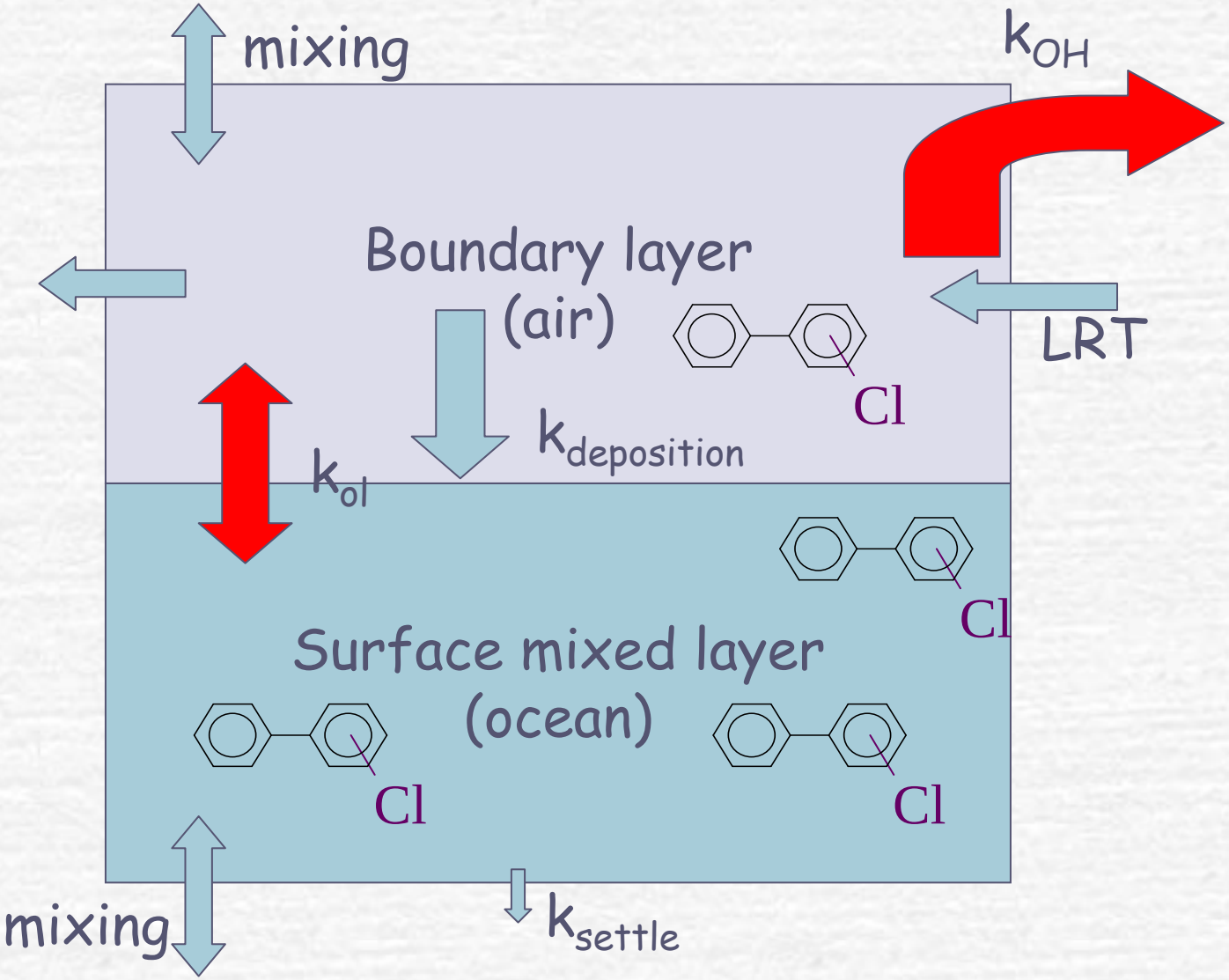
Air-water exchange of PCBs



A simple model



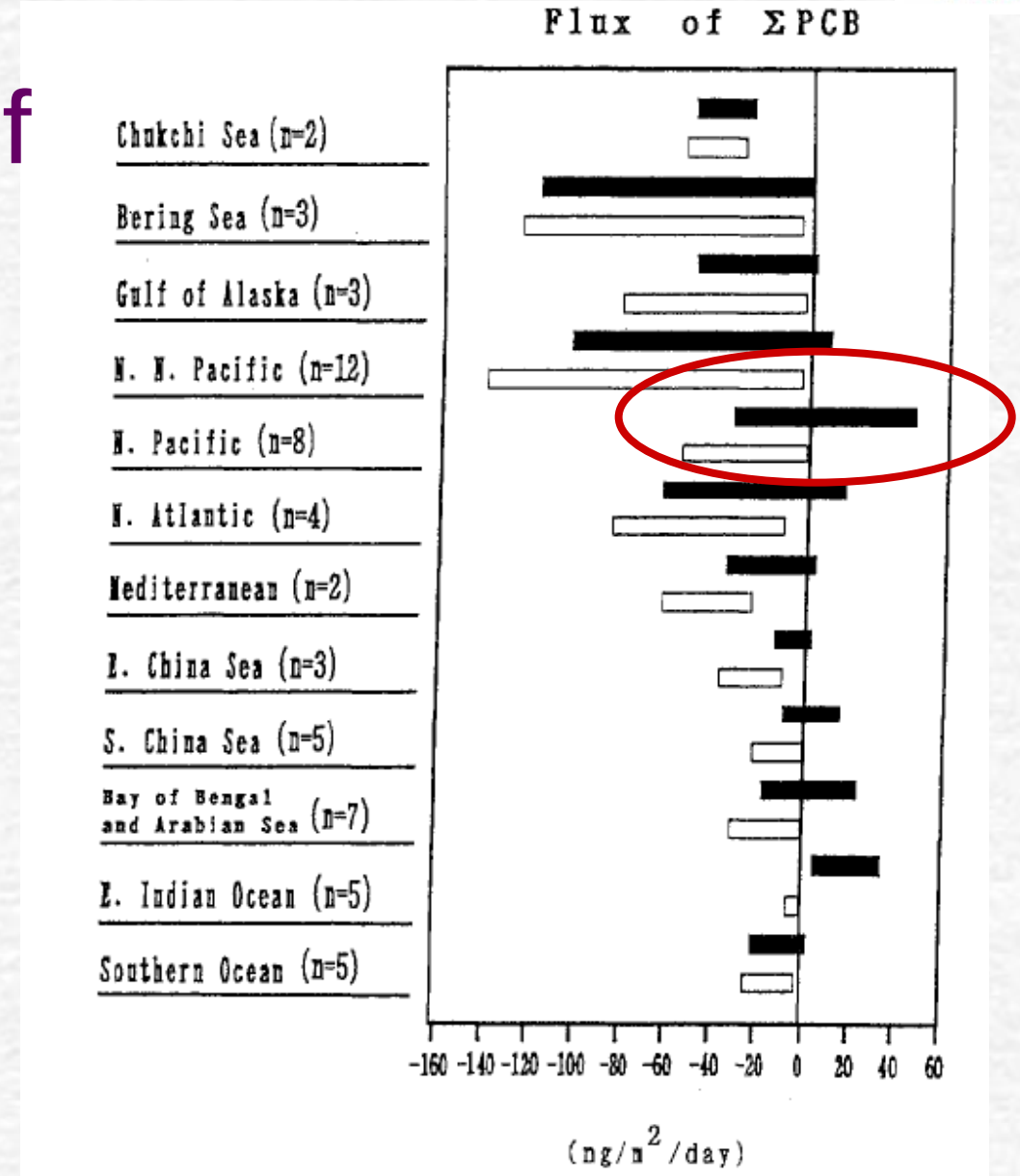
For remote Pacific



Is the remote Pacific a source of PCBs to the atmosphere?

- Validity of sample set.
- Other supporting evidence?
  - Can PCBs survive long enough in the oceans?
  - OH-reaction constant profiles
  - Great Lakes – exception of Lake Superior
  - Previous Pacific cruise results

Air-water equilibrium of PCBs in 1989/90



Iwata et al., 1993

PCBs– $t_{1/2}$ above Great Lakes

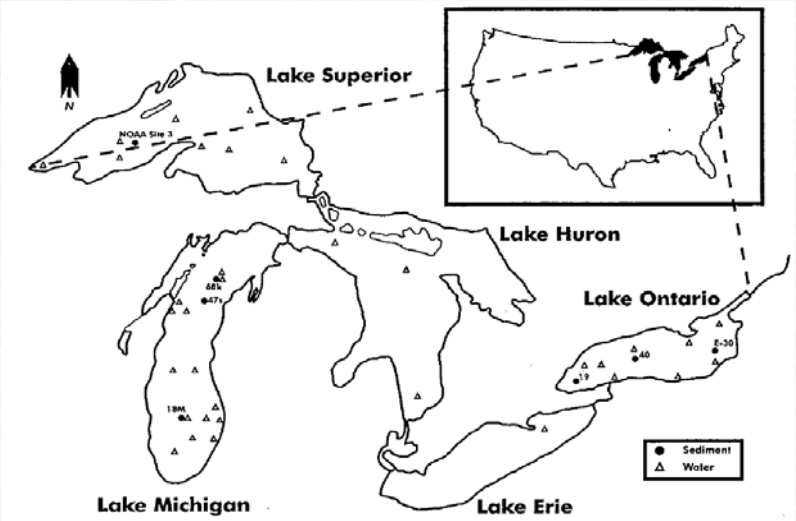
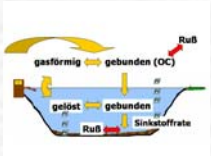


FIGURE 1. Map of the Great Lakes indicating the location of water sampling sites and sediment core sites.

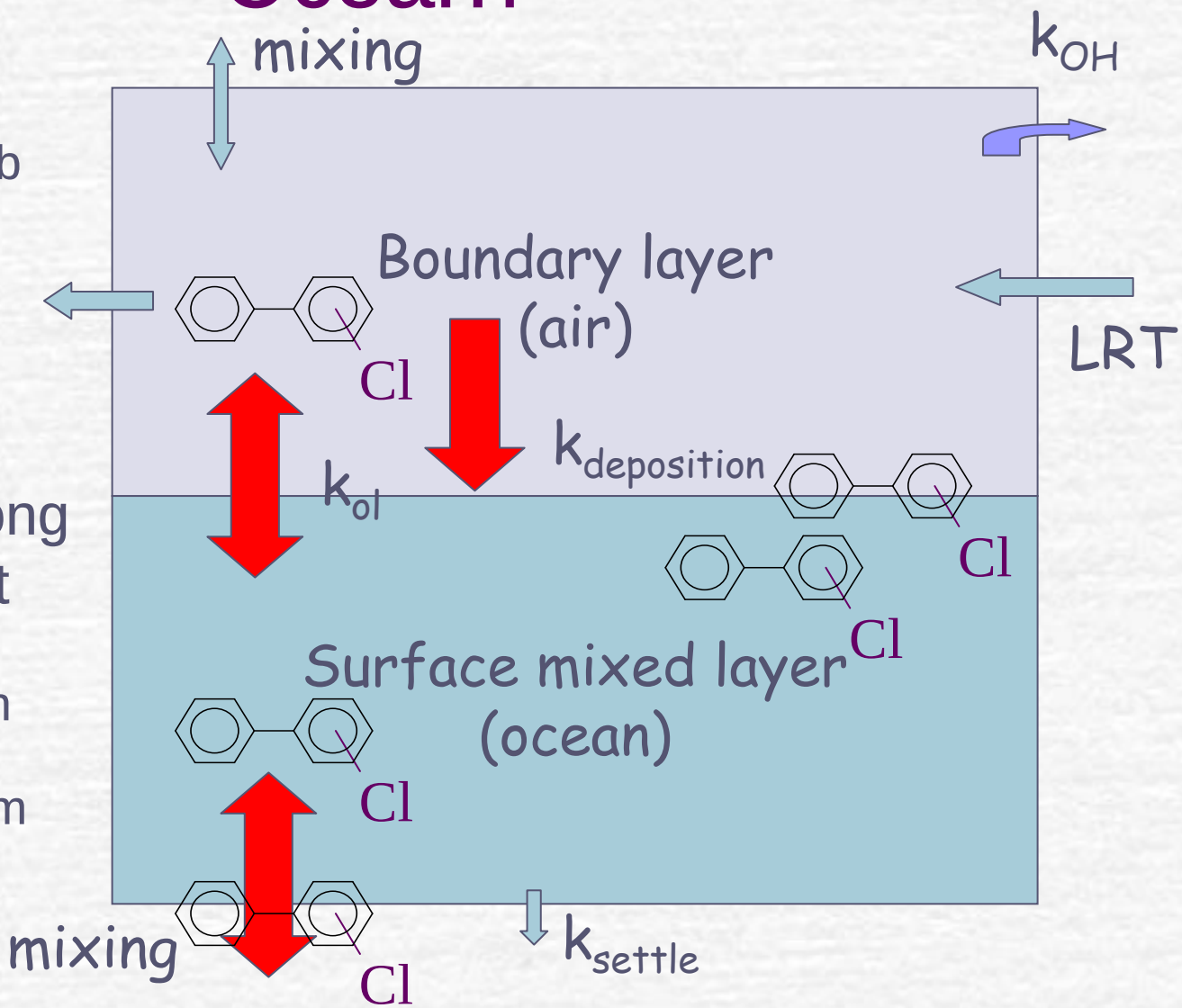
- Decrease of PCBs in Great Lakes' air:
  - $t_{1/2}$ = 11.9 yrs (Chicago IIT)
  - $t_{1/2}$ = 21.6 yrs (Lake Superior)
  - $t_{1/2}$ = 8.8 yrs (Sleeping Bear Dunes, L. Erie)
- Volatilization observed for toxaphene (Swackhamer et al.)
- f (sources, T, OH, **productivity**, change)

Hillery et al., EST'97, Carlson and Swackhamer, unpublished

Can PCBs persist in the remote Ocean?



- OH-radical of PCBs: $t_{1/2}$
  - ~ a week (Lab studies)
  - ~ days (field results)
- NEEDS:
- $t_{res.}$ in water long
- $t_{res.}$ in air short
  - Rain
  - dry deposition and/or
  - Protected from reactions (aerosols)



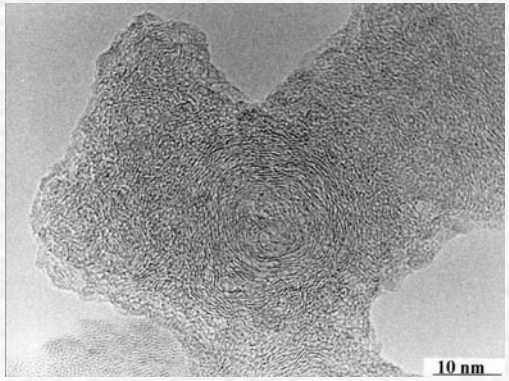
Some summarizing thoughts

- Trophic status of oceans affects POPs' cycling
- Coastal oceans sinks of POPs
- Remote oligotrophic oceans possible long-term buffers of POPs cycling
- Microplastics might matter in Pacific, and retard removal fluxes of POPs

Role of microplastics on transport and fate of POPs

- Microplastics
  ~ 0.05 mg/m^3
  (Bering Sea)
  (Doyle, yesterday)

  Black carbon
  ~ 1-6 mg/m^3
  (Gulf of Maine)
  (Flores and Gschwend)



- Equilibrium partitioning constants
- $K_{\text{Plastic-w}} = c_{\text{Plastic}}/c_{\text{diss}}$
- $K_{\text{BC-w}} = c_{\text{BC}}/c_{\text{diss}}$

Equilibrium partitioning constants

	log $K_{BC\text{-}w}$		log $K_{PE\text{-}w}$
	BH	**NYH**	***Lab***
phenanthrene	6.1± 0.3	5.6 ± 0.3	4.3
pyrene	6.4 ± 0.3	6.4 ± 0.4	5.0
benzo[a]pyr	7.1 ± 0.4	7.4 ± 0.4	6.2
PCB # 52	6.2 ± 0.4	5.9 ± 0.4	5.5
PCB # 66	6.9 ± 0.4	6.7 ± 0.4	6.1

(Lohmann et al., EST, *2005*) (Adams et al., EST, *2007*)

Role of microplastics?

- At concentration of 0.05 mg/m3 their presence has minor effect on POPs cycling *as long as* black carbon particulates are present at ~ mg/m3
- Both will combine to prolong residence time of POPs in Oceans and reduce degradation
- BUT… plastics will transfer POPs from coasts to interior of Oceans
- Time-scales of sorption and desorption ~ 50 – 100s days for pellets

  (Karapanagioti and Kotza, 2008)

Some further thoughts

- Need to better constrain
  - Abundance - transects
  - Sorptive Properties (types of plastic)
  - Sorbed compounds
  - Times of (de-)sorption
  - Problem of size continuum

Global transport and fate of POPs:Water

- With help from
  - Jordi Dachs, Elena Jurado (CSIC Barcelona)
  - Kevin Jones, Linda Gioia, Luca Nizzetto (Lancaster)
  - (Atlantic) *FS Polarstern* and crew
  - Steve D'Hondt and colleagues (URI)
  - (Pacific) *RV Revelle* and crew
  - GLOBALSOC partners
  - Eric Morgan (URI) – 1st vicitim
  - Lin Zhang (Pacific, NABE), Carey Friedman (ICEALOT), Pam Luey (URI)
  - Victoria Sacks, latest vicitim

Many thanks

?

Consequences and challenges of microplastics in the world's oceans

Dr. Joel Baker, University of Washington Tacoma, Tacoma, WA, USA

Abstract: Producing industrial intermediates and consumer products that are persistent in the environment inevitably leads to their global distribution throughout the world's oceans. The re is abundant evidence and numerous examples of this, including the well-told story of the 'global distillation' of semivolatile organic chemicals (*e.g.*, the 'dirty dozen' POPs). Materials susceptible to global transport are those that resist degradation and are poorly removed from mobile reservoirs (*i.e.*, the atmosphere and surface ocean water). Due to their chemical stability and near neutral buoyancy, it appears that microplastics meet these criteria, as supported by the increasing number reports documenting microplastics in remote marine environments. It is also now clear that microplastics may enter marine food webs, primarily through inadvertent ingestion, that components of the plastic may leach into seawater, and that other chemical contaminants can adsorb to microplastics. While parts of the story are emerging, the overall impact and consequences of marine microplastics has not yet been articulated. Significant scientific uncertainty remains, especially surrounding the potential biological impacts and the role of microplastics in controlling chemical contaminant exposure and cycling. For example, one might argue that microplastics scavenge pollutants from seawater into highly concentrated, easily ingested packages, resulting in enhanced exposure to marine organisms. Conversely, this 'packaging' can be viewed as a competitive 'protection', where the microplastic-bound pollutants are sequestered in a non-bioavailable form. Assessing the risk of marine microplastics depends on resolving these uncertainties.

Joel Baker, PhD holds the Port of Tacoma Chair in Environmental Science at the University of Washington Tacoma. He earned a B.S. degree in Environmental Chemistry from the State University of New York in Syracuse, and M.S. (1985) and Ph.D. (1988) degrees in Civil and Environmental Engineering at the University of Minnesota. Between 1988 and 2007, he was a member of the faculty of the University of Maryland Center for Environmental Science's Chesapeake Biological Laboratory. Dr. Baker's lab studies the transport of organic contaminants in the atmosphere and in surface waters, specifically atmospheric transport and deposition of organic chemicals, aerosol particle chemistry, the dynamics of contaminant transport in estuaries, and the exposure and transfer of bioaccumulative chemicals in aquatic food webs. He has co-authored over eighty papers on contaminant cycling in the Great Lakes, the Chesapeake Bay and coastal waters, and edited *Atmospheric Deposition of Contaminants to the Great Lakes and Coastal Waters* (SETAC Press, 1997). He was the lead author on a scientific review of PCBs in the Hudson River, a contributing author to the Pew Oceans Commission report *Marine Pollution in the United States*, and a member of the national Research Council's Committee on Oil in the Sea, chaired the New York/New Jersey Harbor Contaminant Assessment and Reduction Program's Model Evaluation Group, advised the European Commission on water quality modeling, and served on the Board of Directors of the Society of Environmental Toxicology and Chemistry. Dr. Baker is the Science Director of the Center for Urban Waters in Tacoma, WA and recently elected as chair of the Puget Sound Partnership Science Panel.

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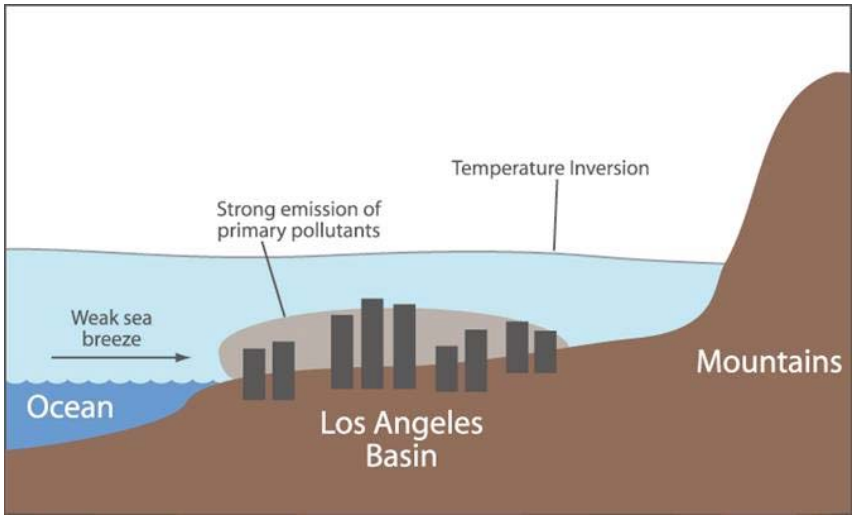
Joel Baker

The Center for Urban Waters
University of Washington Tacoma

1. Transport matters



1. Transport matters (con't)

Land-based sources of microplastics

- deterioration of beach debris
- point-of-use release
- sewage sludge
- stormwater

Conduits to the ocean

- shoreline erosion
- rivers
- outfalls

Estuaries as particle traps

2. Form matters

Hard surfaces are important marine microhabitats

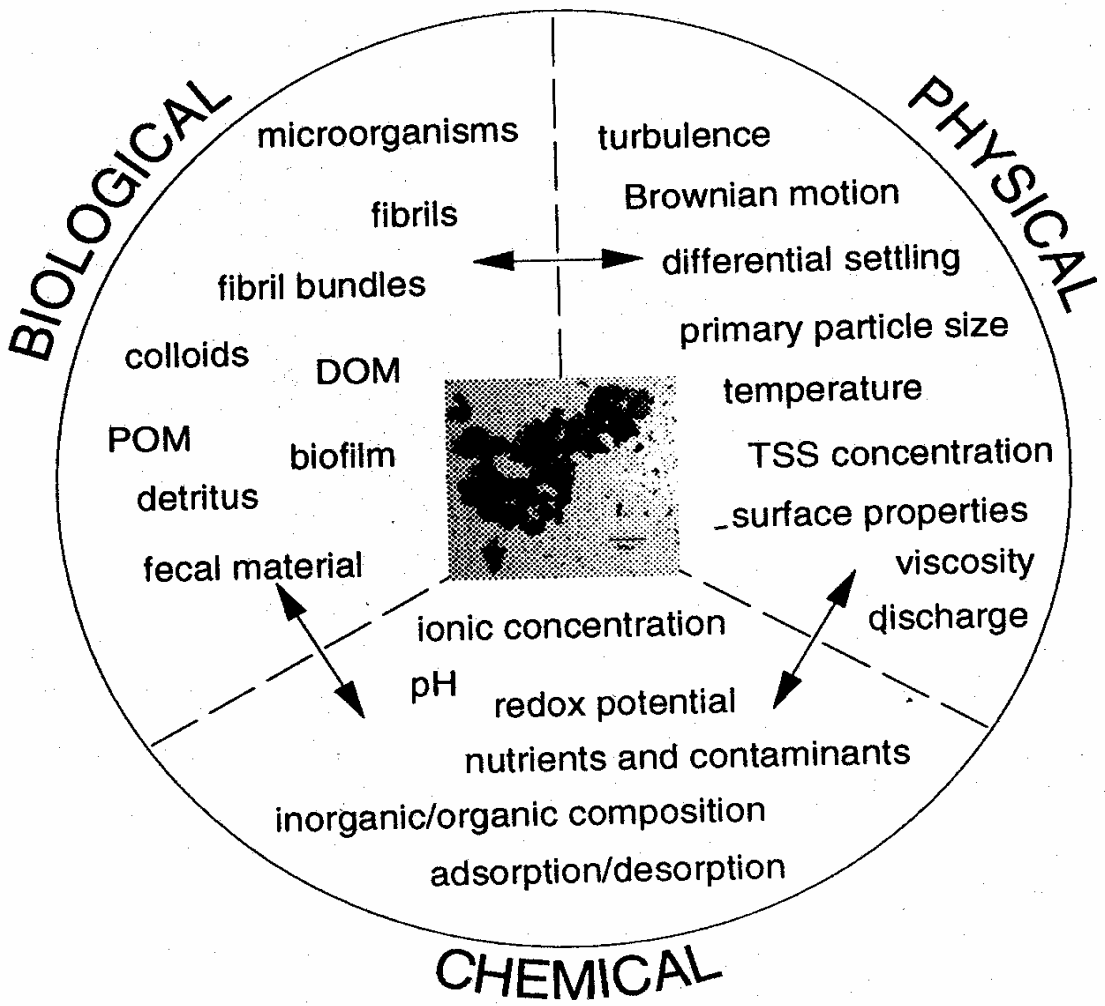
Biofilms alter:

- surface properties
- aggregation potential
- sorptive chacteristics
- nutritional/taste?

Unlikely that individual, ‘clean’ microplastic particles exist In seawater

Larry Madin, WHOI

Cohesive Sediment Forms Flocs



From Droppo *et al.* 1997

Properties of flocs determine residence time

3. Microplastics as a source of pollutants?

- Speculative calculation: brominated flame retardants added to plastics
  - Bromodiphenyl ethers = 0.1% by weight in electronic casings (Allen et al., *EST*, 2008, 42, 4222-4228.)
  - [BDE] in Arctic rivers = 3-5 pg/L (Carroll et al. *EST*, 2008, 42, 69-74)
    - This corresponds to 3-5 ng/L of microplastics in river water (0.003-0.005 mg/m3)
  - [plastic] in California coastal water = 20-300 ng/L (M. Doyle)
    - This corresponds to 20-300 pg/L of BDE in these waters

- Microplastic impacts most likely near sources and in areas that naturally accumulate small particles
- Better information about primary microplastic sources is needed
- Understanding link between sources and sinks of microplastics will require deterministic transport modeling of aggregates that accounts for weathering
- Levels of some POPs in remote environment may be consistent with a microplastic source, but this requires much more study.

APPENDICES

APPENDIX A: WORKSHOP AGENDA

Tuesday, 9 September 2008

CARWEIN AUDITORIUM, KEYSTONE BUILDING, UNIVERSITY OF WASHINGTON TACOMA

08:30 Coffee and Registration

09:00 Opening remarks – *Dr. Pat Spakes*, Chancellor, University of Washington Tacoma, *Dr. Joel Baker*, University of Washington Tacoma, *Doug Helton,* National Oceanic and Atmospheric Administration, Marine Debris Program

09:15 Keynote Address – How concerned should we be about microplastics?
Dr. RC Thompson, University of Plymouth, Plymouth, UK

10:15 Break

SESSION I: Occurrence of small plastic debris in the marine environment

10:30 Fate of Plastics Debris in the Marine Environment
Dr. Anthony Andrady, Research Triangle Institute, Durham, NC, USA

11:15 Microplastics as accumulators and sources of persistent organic pollutants in marine food webs: how significant?
Dr. Alan Mearns, NOAA Office of Response & Restoration, Seattle, WA

12:00 Lunch

13:00 The oceanography, biology, and fisheries of the North Pacific
Dr. Mike Seki, NOAA National Marine Fisheries Service, Honolulu, HI, USA

13:45 Small Plastic Debris and Plankton: Perspectives from NOAA Plankton Sampling Programs in Northeast Pacific Ecosystems
Dr. Miriam Doyle, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA, USA

SESSION II: Impact of small plastic debris on the marine environment

14:30 Foolish Fulmars and their contribution to ecological quality
Dr. Jan A. van Franeker, Wageningen IMARES, Den Berg (Texel), THE NETHERLANDS

15:15 Break

15:30 Incidence of marine debris ingestion in seabirds from Midway Atoll and Heard Island
Dr. Heidi J. Auman, University of Tasmania, Hobart, Tasmania, AUSTRALIA

16:15 Ingestion of microplastics by marine invertebrates
Dr. Richard Thompson, University of Plymouth, Plymouth, UK

17:00 Translating scientific findings into action: California's response to plastics in the environment
Dr. Stephen Weisberg, Southern California Coastal Water Research Project, Costa Mesa, CA, USA

17:45 Adjourn – *Dr. Joel Baker*

18:30 Reception and Dinner
The Tacoma Club, Wells Fargo Plaza, 1201 Pacific Avenue, 16th floor

Wednesday, 10 September 2008

CARWEIN AUDITORIUM, KEYSTONE BUILDING, UNIVERSITY OF WASHINGTON TACOMA

08:00 Opening remarks – *Dr. Joel Baker*

Session III: Impacts of small plastic debris exposure to persistent organic pollutants

08:15 Effect of sorbent particulate amendments on PCB bioavailability in sediments
Dr. Upal Ghosh, University of Maryland Baltimore County, Baltimore, MD, USA

09:00 International Pellet Watch: Global distribution of persistent organic pollutants (POPs) in marine plastics and their potential threat to marine organisms
Dr. Hideshige Takada, Tokyo University of Agriculture and Technology, Tokyo, JAPAN

9:45 Microplastic-pollutant interactions and their implications in contaminant transport to organisms
Dr. Emma Teuten, University of Edinburgh, Edinburgh, UK

Session IV: Effect of oceanic small plastic debris on biogeochemical cycling of POPs

10:30 Role of microplastics on transport and fate of POPs
Dr. Rainer Lohmann, University of Rhode Island, Providence, RI, USA

11:15 Wrap-up: Consequences and challenges of microplastics in the world's oceans
Dr. Joel Baker, University of Washington Tacoma, Tacoma, WA, USA

12:00 Lunch Media Availability – Tacoma Room

Session V: Breakout Groups

1:00 Introduce breakout sessions
A. Sources (accumulation) and sinks (uptake) of plastics in the marine environment (GWP 212)
B. Importance of physical impacts (ingestion) vs. other impacts of microplastic debris (GWP 216)
C. Overall accumulation of microplastics in organisms, potential to bioaccumulate POPs (GWP 220)

1:30 Breakout groups discuss their perspectives on major questions

15:00 Break

15:30 Reconvene to discuss breakout group reports (Carwein Auditorium)

16:15 Discussion of future research initiatives

17:00 Closing Remarks and Adjourn Workshop – *Dr. Joel Baker*

Thursday, 11 September 2008

Session VI: Preparation of Workshop Proceedings (Cherry Parkes 103)

8:30 - 12:00 Steering Committee only

APPENDIX B: CHARGE TO BREAKOUT GROUPS

Session V: Breakout Groups

A. Sources and sinks of plastics in the marine environment

Lead*: Anthony Andrady
Rappateur: Nir Barnea
Participants: Miriam Doyle, Michael Seki, Dave Foley, Dominic Gregorio, Pete Dinger, Marcus Eriksen, Joseph Greene
Location: GWP 212

B. Effects of microplastic debris on marine organisms

Lead*: Richard Thompson
Rappateur: Kris McElwee
Participants: Heidi Auman, Jan van Franeker, Ashley Greene, LeeAnn Woodward, Beth Phillips, Doug Helton
Location: GWP 216

C. Role of microplastics in POP cycling and exposure

Lead*: Rainer Lohmann
Rappateur: Amy Merten
Participants: Alan Mearns, Shige Takada, Emma Teuten, Tara Conrad, Benjamin Applegate, Aja Reyes, Fung-chi Ko, Stan Phillippe
Location: GWP 220

Charge to breakout groups

1. Review white paper for any major omissions of published literature.

2. Identify key gaps in our current knowledge. Are there any products, techniques, or technologies required that are not currently available?

3. Describe potential research projects and best methods to achieve filling the gaps in research.

*The lead should be prepared to present the breakout group's collective thoughts to the workshop participants.

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APPENDIX D: GROUP PHOTOGRAPH

International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris. Photo taken on the University of Washington Tacoma campus, 9 September 2008.

<u>From left:</u> D. Gregorio, E. Teuten, M. Eriksen, C. Morishige, B. Applegate, D. Foley, M. Doyle, E. Phillips, S. Weisberg, C. Arthur, H. Takada, R. Lohmann, U. Ghosh, R. Thompson, J. van Franeker, S. Phillippe, P. Dinger, J. Greene, M. Seki, F. Ko, A. Mearns, K. McElwee, J. Baker, N. Barnea, L. Woodward, A. Merten, D. Helton, H. Auman, A. Greene, A. Reyes

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