23. 08-0297 Recommendation to direct the Federal Legislation Committee and the City Manager to identify federal resources to study and implement solutions to reduce trash debris and pollution associated with the Los Angeles River, including the possibility of including the Los Angeles River as a project in the Water Resources Development Act.

REMARKS BY CAPTAIN CHARLES MOORE
ALGALITA MARINE RESEARCH FOUNDATION

148 N. Marina Drive, Long Beach, CA 90803

Including Supporting Documentation

Mayor Foster and Members of the City Council: The ocean is downhill from everywhere and the Los Angeles River is the principal conveyance for both debris of human origin and what Long Beach's Clean Water Program Officer, Tom Leary, calls "Urban Slobber." In 2003, the State Water Resources Control Board, awarded $482 thousand dollars to Algalita Marine Research Foundation to quantify the major component of man made debris, plastic products and pellets. I have prepared folders for each of you with the results of that study as well as a summary manuscript on the marine debris issue, currently in press at the journal Environmental Research, which discusses some proposed solutions, and our Marine Pollution Bulletin paper comparing surface plastic and zooplankton in Long Beach's coastal waters. After having spent the last decade studying the effects our debris is having on the Pacific Ocean, I have concluded that its deleterious effects are great and urgently need to be addressed. Stopping the debris before it reaches the ocean is the only viable solution, for once it reaches the sea it is transported by wind and currents to meet its counterparts from the rest of the North Pacific Rim, and after 12 years, a NOAA model has 75% of all North Pacific debris converging on an area of the Central Gyre equal to 28% of the total area. Published studies by the Southern California Coastal Water Research Project and AMRF have documented six times as much plastic waste floating in this area as zooplankton, the natural base of marine food webs. The gyre is a cementary for this debris where it resides for decades, breaking into ever smaller bits until it becomes individual polymer molecules. These tiny bits are vacuumed up by nature's most efficient vacuum cleaners, the ocean's filter feeders.

The Long Beach Post's political notebook states that, "After several weeks in the first half of March battling sexual predators, the Long Beach City Council starts April off with a safer topic—battling L.A. river pollution. While marine debris does not rape or molest in the conventional sense of those terms, it is implicated as a transport mechanism for those components of urban slobber that can alter sexuality. Indeed, plastic phthalate additives have been banned in California for that very reason. Not only does our debris sexually molest by introducing endocrine disruptors into the food web, it often kills its hundreds of thousands of victims annually by strangulation with nets, lines and bands, and also starvation, since it can fill stomachs without providing nutritional benefits.

I spent the last six months sampling 7000 miles of the North Pacific Gyre along with Dr. Marcus Eriksen, who is currently building a boat of plastic junk in front of the Aquarium of the Pacific which will sail to Hawaii in May to dramatize the seriousness of the debris issue. What we documented in the center of our vast ocean was truly alarming. The Pacific has become a plastic soup with untold numbers of plastic particles and pieces of trash covering it like a very loose nit fabric whose mesh size is decreasing rapidly. I applaud the Council for its initiative to look for substantial funding to fight this threat. Circling the wagons of local cities to resist the TMDLs a la Larry Forrester's Coalition for Practical Regulation only delays the inevitable. Although Long Beach does not manufacture, sell or profit from the trash that becomes marine debris, it is charged with its cleanup. Bold measures must be sought to deal with this problem effectively. A rain swollen river flowing at 40 miles per hour cannot be boomed effectively. Settling arms of the river must be created upstream to collect debris and filter slobber. The feasibility of multi-use constructed wetlands should be a focus of Federal funds, and the producers of fast track trash and non-recyclable waste must be held to account.

Thank you,
Captain Charles Moore
Founder, Algalita Marine Research Foundation
www.Algalita.org

REDUCE - REUSE - RECYCLE

- Buy in bulk and bring your own cloth or recycled grocery bags to the store
- Keep litter, leaves and debris out of the street gutters and storm drains
- Reuse whenever possible
- Reduce consumption by avoiding excessively packaged products
- Use environmentally friendly cleaners or products that are low in phosphorous to reduce the amount of nutrients discharged into our lakes, streams and coastal waters
- Choose products packaged in recycled materials

Join the Algalita Marine Research Foundation (AMRF)

AMRF is a 501c(3) nonprofit organization founded in Long Beach, California and is dedicated to the protection of the marine environment through research and education. Our primary work is to establish a baseline data set of the level of plastic debris found in our oceans and inform the public about its existence through public education.

Membership Levels

Basic Membership	**$25**
Friend of Algalita	**$50**
Good Friend of Algalita	**$100**
Great Friend of Algalita	**$150**

A membership donation of $500 or more will receive an AMRF t-shirt and a *"Research Clips"* video.

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e-mail ______________________

Send by mail or fax.

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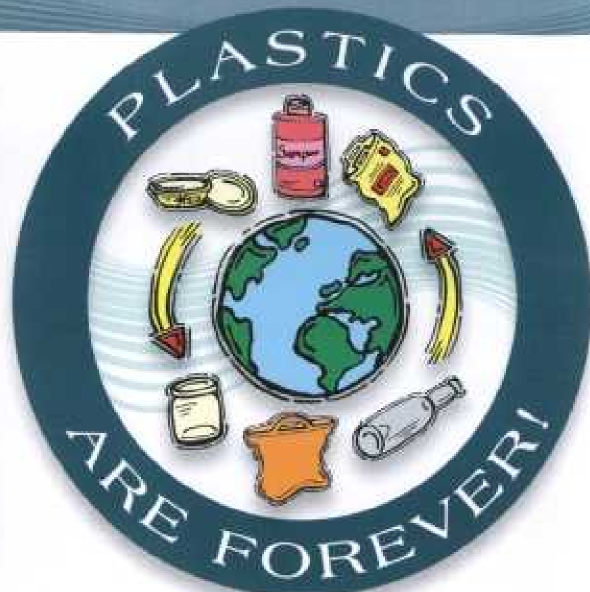
www.algalita.org
www.plasticdebris.org

Algalita Marine Research Foundation



We drink out of them, eat off of them, sit on them and even drive in them. They are durable, lightweight, and can be made into virtually anything. But it is these useful properties of plastics which make them so harmful when they end up in the environment.

Plastics, like diamonds... ARE FOREVER!

- Only 3.5% of plastics are recycled in any way
- 63 pounds of plastic packaging goes into landfills in the U.S. per person per year.
- Broken, degraded plastic pieces outweigh surface zooplankton in the Central North Pacific by 6 to 1.

Why is plastic in the ocean a problem?

Because plastic does not biodegrade. When something biodegrades, naturally occurring organisms break down natural materials into their simple chemical components. Paper, when it breaks down, becomes carbon dioxide and water. But plastic, a synthetic material, never biodegrades. Instead, plastic goes through a process called photodegradation, where it is broken down by sunlight into smaller and smaller pieces, all of which are still plastic polymers. Even this degradation process can take a very long time. Estimates of 500 years for a disposable diaper, 400 years for a plastic six-pack ring and 450 years for a plastic bottle have been made. The more plastic we produce, the more we have to live with... *forever!*

The ocean is especially susceptible to plastic pollution, because:

1. It takes longer for the sun to break apart a piece of plastic in the ocean than a piece of plastic on land. This is because the ocean water cools the plastic piece, prevents heat build-up and limits UV light exposure.

2. Plastics are carried by currents, which can concentrate the plastic in certain areas and prevent it from washing onshore. Circulating currents in the ocean caused by stable weather patterns are called "gyres." When plastic is flushed out of a gyre by storms and washes ashore, or when rain sends plastics down rivers to the sea, much of it is mixed into beach sand and can never be recovered.

Some fish mistake plastic "nurdles" for food.

But plastic pollution doesn't just look bad...

Plastic pollution is bad for the millions of animals that inhabit our ocean waters and for the people who fish, swim and recreate there.

Many marine birds and animals mistakenly eat pelagic (free-floating) plastic.

- Often these animals cannot distinguish plastic from food. Plastic, because of its high molecular weight and the nature of its chemical bonds, can never be digested. It provides no nutrients. Eating plastic can cause animals to feel full and not hungry even though they are not actually consuming food. In birds, it has been shown that ingestion of plastics can prevent migration and reproduction, and can eventually cause starvation and death. In turtles, plastic has been shown to block intestines and make the animals float so that they cannot dive for food.
- Toxic chemicals in plastics can make marine birds and animals sick. Over 80 species of seabirds have been found to ingest plastic. Sea bird chicks are especially vulnerable as they receive high levels of pollution from the yolk sac and, after hatching, from food brought by their parents.
- Ninety percent of Laysan Albatross chick carcasses and regurgitated food boluses contain plastic.
- Marine birds and animals can become entangled in plastic nets and fishing line. An estimated 100,000 marine mammal deaths occur this way each year in the North Pacific.
- Chemicals used to make plastics can escape into the atmosphere during the manufacturing process. Fourteen percent of the toxic airborne chemicals nationally are from "plastics sector" releases. These chemicals can be toxic or carcinogenic, harming both people and animals.

A plastic bottle takes 450 years to degrade.

The plastic future looks grim.

Virgin plastic pellets are released into the environment by thousands of consumer plastics manufacturers and are the most common contaminant on some beaches.

Scientists predict a 10-fold increase in ocean plastics by the year 2010, which would bring the ratio of surface plastic to zooplankton in the North Pacific Central Gyre to 60:1 by weight.

What are the facts about plastic?

The magnitude of our plastic problem is enormous.

- The American people weigh approximately 50 billion pounds, but 100 billion pounds of plastic resin pellets (the raw materials for consumer plastics) are produced in the U.S. annually.
- 63 pounds of plastic packaging goes to landfills in the U.S. per person per year.

Only 3.5% of plastics are recycled in any way.

- Only 3.5 % of plastic is recycled in any way. Reheating plastic gives it a "heat history" which reduces its flexibility. Reheating temperatures are too low to burn off contaminents; therefore, very few plastics are recycled into the same type of container or product that they were originally. Usually, recycled merely means collected, not reprocessed into useful products.
- The "chasing arrows" symbol (shown above) only denotes type of plastic; otherwise it is meaningless. Plastics manufacturers adopted the symbol over the protests of environmentalists and are now being challenged in court by several cities over its implications.

How are plastics getting in the ocean?

Approximately 100 million containers are shipped annually over the world's oceans. Shipping across the North Pacific Ocean from Asia to North America is along Great Circle routes in the West Wind Drift current at the northern edge of the Central Pacific Gyre. Frequent severe storms along this route cause the loss of hundreds of containers overboard each year contributing, among other plastics, tens of thousands of shoes and millions of plastic shopping bags made in Asia.

Only about 20% of ocean pollution comes from activities at sea. Activities on land contribute most of the remaining 80%.

Because of their buoyancy and persistence, plastic items contribute disproportionately to the overall impact of marine debris. Most of the debris that either entangles animals or is found in their stomachs is made of plastic.

The majority of the plastic that ends up in the Central Pacific Gyre (an area the size of Texas) has been shown to circulate there for at least twelve years. Debris lost in the Bering Sea or the western portion of the Subarctic Gyre will end up there in 3 to 6 years.

Not all plastic floats on the surface. Approximately half of plastics are negatively buoyant. They therefore do not receive sunlight to facilitate the photodegredation process that breaks them into smaller pieces. This debris accumulates on the bottom of the ocean or "benthos." There the particulates are used by polychaete worms to make their dwelling tubes and some are eaten by flounders and lobsters. The nets, traps and lines that do not photodegrade continue to "ghost fish" (catch fish without a fisherman) and entangle fish and mammals for years.

SIX MISCONCEPTIONS ABOUT PLASTIC

1. **Plastics that go into curbside recycling bins get recycled.**
   FACT: Most do not.
2. **Curbside collection reduces the amount of plastic land filled.**
   FACT: It does not.
3. **Packaging resins are made from petroleum refinery waste.**
   FACT: Nearly all are made from virgin petroleum and natural gas.
4. **Plastic recyclers promote its recyclability.**
   FACT: Plastic resin pellet producers pay for recycling ads to promote the sale of plastics.
5. **Using plastic containers conserves energy.**
   FACT: Most of the energy costs of plastic are incurred by the manufacturer. Virgin glass uses an equal amount of energy, while recycled glass uses far less than either virgin plastic or virgin glass.

6. **Our choice is limited to recycling or wasting.**
   FACT: Source reduction is key, and quite simple.

The History of Plastics

1869
John Wesley Hyatt invents celluloid, the first plastic product given a trade name

1909
Bakelite is introduced to the Chemist Club in NY as the "first thermoset plastic," meaning once set, it was set for life.

1939
Nylon stockings debut at the World's Fair.

1946
Earl S. Tupper produces a 7-ounce polyethylene tumbler, the first of many products available form Tupperware Home Parties, Inc.

1955
The Corvette is the first car to use plastic for body panels.

1957
Monsanto's House of Tomorrow, completely made of plastic, opens at Disneyland. The Hula Hoop creates a surge in demand for polyethylene

1983
Microwave ovens open up a new market for plastic packaging.

2000
In the U.S., pre-production plastic reaches 100 billion pounds of virgin resin pellets per year.

What we do know about the North Pacific Ocean.

Scientists have been studying the problem of plastic floating pollution in the area since the 1970's. These are some of their findings over the last few decades:

- In a 1999 study, the North Pacific Central Gyre was found to contain six pounds of plastic for each pound of surface zooplankton.
- The results of studies done in the 1990's indicate that the quantity of plastic has tripled in the last ten years from maximum densities of 320,000 particles per square kilometer to 1 million particles per square kilometer.
- The filter-feeding animals in this area, mucous web feeding jellies and salps, were found to be heavily impacted by plastic fragments. The smaller the fragments, the fewer of them were found to be free floating, indicating that filter feeders had caught them.
- Filter feeders are at the lower end of the food chain, and fifty species of fish and many turtles are known to eat them, thus accumulating plastic in their stomachs.
- Plastic materials accumulate and concentrate organic chemicals and environmental pollutants up to one million times their concentration in the surrounding sea water. Many of these chemicals are called "endocrine disruptors", and can be released when the plastics are ingested. The endocrine system produces hormones in humans and animals.
  - Hormones are amazingly potent. Estradiol, the body's key estrogen hormone, operates at a concentration in the part per trillion range. One part per trillion is equivalent to one drop of water in 660 rail tank cars – a train 6 miles long.
  - Effects of hormone disruption on humans run the gamut from enlarged prostates and cancer to early puberty in young girls, even mental retardation and propensity to violence. In fish it can cause males to become female or fail to produce sperm.

For more information our video "Synthetic Sea: Plastics in the Open Ocean" is available from AMRF for $20 per copy.

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Join the Algalita Marine Research Foundation

If you want to help preserve the marine environment, please become a member. We are a 501 c(3) organization and contributions are tax deductible. An annual membership donation of as little as $25 will help support our research and education programs.

Membership Levels:

Basic membership	$25
Friend of Algalita	$50
Good Friend of Algalita	$100
Great Friend of Algalita	$250

A membership donation of $500 or more will receive an AMRF T-shirt and educational video.

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e-mail: info@algalita.org

Sign-up online:

www.algalita.org

www.plasticdebris.org

What is the Algalita Marine Research Foundation?

The Algalita Marine Research Foundation (AMRF) is a Long Beach, California based non-profit environmental organization. Our mission is to restore and preserve coastal, near-shore and off-shore marine environments through ecological stewardship.

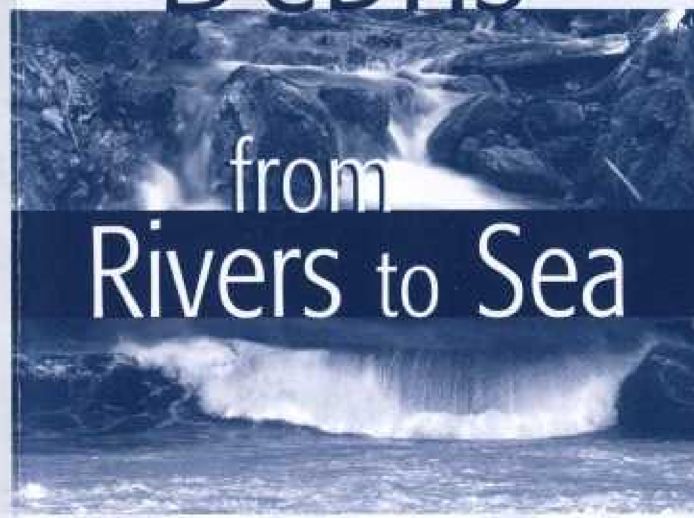
With the help of its chartered research vessel, The Oceanographic Research Vessel (ORV) Alguita, AMRF is committed to:

- Gather, publish and present quality scientific information.
- Engage in local and global marine projects, and assist others in the same.
- Produce quality marine awareness educational programming.
- Positively influence public policy for marine protection.

Algalita Marine Research Foundation

www.algalita.org

Plastic Debris from Rivers to Sea



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Why care about plastic debris?

Plastic debris is proliferating in the environment, especially in the marine environment, and is causing numerous problems for humans and wildlife. Plastic is not biodegradable and very little of it (less than 4%) is recycled. (The triangle of arrows around a number doesn't mean that a plastic product is recyclable.) Because it is durable and light-weight, plastic debris travels over vast distances and accumulates on beaches and in the ocean. The majority of marine debris is plastic.

In the Central North Pacific Gyre, pieces of plastic outweigh surface zooplankton by a factor of 6 to 1. Ninety percent of Laysan Albatross chick carcasses and regurgitated stomach contents contain plastics. Fish and seabirds mistake plastic for food. Plastic debris release chemical additives and plasticizers into the ocean. Plastic also adsorbs hydrophobic pollutants, like PCBs, and pesticides like DDT. These pollutants bioaccumulate in the tissues of marine organisms, biomagnify up the food chain, and find their way into the foods we eat.

Although plastic products benefit our lives in the medical industry, safety equipment and other technologies, it is imperative that we eliminate the flood of post-consumer plastic waste into the environment. For the sake of a healthy biosphere, including ourselves, the plastic plague must no longer be ignored.

How did the plastic get there?

Estimates of plastic in the world's oceans exceed 100 million tons. Though 20% comes from ocean sources like derelict fishing gear, 80% comes from land, from our watersheds. A large segment of what ends up as marine debris is single use disposable consumer items. A bottle cap or plastic bag that falls to the grounds will be blown or washed into a storm drain, where it will flow to the ocean. Beachgoers also contribute to the problem, as does the plastics industry – roughly 10% of the debris found on beaches is preproduction plastic pellets lost during industrial processing.

What is a watershed?

Every human lives in a watershed – an area that is drained by rivers and streams and includes geographical structures like mountains, valleys, and man-made structures like buildings, parking lots and highways. It also includes a rich biodiversity that is supported by the ecosystems within it.

There are many strategies to keep plastic out of our watersheds and out of the ocean. Structural controls, like screens over storm drains and nets across rivers are marginally successful and expensive. Beach and reef clean-ups are infrequent. Solutions are most effective at the source. Best management practices by plastic manufactures work when enforced. Some communities have banned certain plastics from retail use. Bio-plastics, polymers made from plants, are excellent alternatives that will help end the plastic plague.

10 things you can do to conserve your watershed.

1. HOUSEHOLD CHALLENGE: Create a 100% recyclable and compostable grocery list. Imagine all of your household waste going into the compost pile or recycle bin!
2. If you must buy consumable products, choose paper, glass or bio-plastic.
3. Sweep sidewalks, don't hose them.
4. Use natural pest killers in your garden, such as ladybugs, decollate snails, or praying mantis eggs. Use pesticides sparingly.
5. Dispose of used oil, antifreeze, paints, and other household chemicals at a hazardous waste facility, not in storm drains.
6. Keep vehicles well maintained. Clean up spilled brake fluid, oil, grease, and antifreeze with a rag or absorbent compound.
7. Wash your car on the lawn so that the water sinks in the ground. Use environmentally friendly cleaners.
8. Purchase household detergents and cleaners that are low in phosphorous to reduce the amount of nutrients discharged into our lakes, streams and coastal waters.
9. Ask your community to install screens over storm drains, and help keep them free of litter, leaves, and debris.
10. Buy in bulk, and bring your own cloth or recycled grocery bags to the store.

Flotsam & Jetsam

Algalita Marine Research Foundation

RESEARCH • EDUCATION • RESTORATION

1ST QUARTER 2008

currents

Plastic In the News

City of Capitola Enforcing Polystyrene Ban

Synopsized by Cathy Cressy-Torrones

On September 27, 2007 the City of Capitola, CA passed Ordinance 913 which prohibits the use of polystyrene take out containers. Dustin Macdonald, Co-Chair Surfrider Santa Cruz Chapter, declared the community of Capitola, Surfrider, and AMRF all vital players in this latest victory in the fight against plastics.

Macdonald notes that after literally hundreds of letters, emails and calls by community and Surfrider members, the city of Capitola, located along the Monterey Bay National Marine Sanctuary, "became the first city within the sanctuary to enforce such a ban." A few other municipalities are hot on their heels, including Santa Cruz and Pacific Grove in Monterey County.

The city website declares that Capitola, "joins an estimated 100 cities throughout the country, including Berkeley and Oakland, in regulating polystyrene foam food service ware." The ordinance allows restaurants and food vendors to charge customers a small "take out" fee to cover the cost of approved packaging. In addition, thru the City's website, a list of companies that manufacture or distribute environmentally safe food service ware is available, as is a link to AMRF's *Plastic Debris, Rivers to Sea* project.

For more information see:
www.ci.capitola.ca.us
www.surfridersantacruz.org

AMRF Scours the Seas in Search of Trash

By Corinne Heyning

Fall 2007 marked the fifth time in ten years that Captain Charles Moore, Algalita Marine Research Foundation (AMRF) founder, set out for a 2000 mile voyage aboard the ORV *Alguita*. Five volunteers accompanied him: Lorena Rios, Ph.D, chief scientist aboard the ship; Joseph Goodman, First Mate and ship doctor; and three film crew members from VBS TV. Their destination: the Eastern North Pacific Garbage Patch. Their purpose: to cull, tally, quantify and distill plastic and other garbage from the ocean.

AMRF undertook this expedition in hopes of answering such questions as: What kind of garbage is out there? How much is there? Where does it come from? And how polluted are the plastic fragments floating between the surface down to 300 feet below sea level?

To find answers, Captain Moore set a course 1,000 miles west of California and 1,000 miles north of the Hawaiian Islands, to an area nicknamed the Garbage Patch. This area of isolated sea earned its moniker because of the way ocean currents and trade winds create a gyre that collects debris. On this voyage, instead of finding an isolated patch of garbage, Captain Moore found a "super highway" of junk running between San Francisco and Japan. In the middle floats a concentration of trash.

"We were shocked by our inability to get out of this garbage system," says Captain Moore, who believes that the amount of plastic found during this voyage could be ten times higher than that documented in 1999. Preliminary findings corroborate his suspicions. Some samples have proven to harbor as much as 48 parts plastic to 1 part zooplankton, which is significantly more than the 6:1 ratio documented on the first voyage in 1999.

Continued on page 5

Captain Moore prepares to attach a NOAA tracking buoy to a ghostnet.

Algalita on the Banks of the L.A. River

By Corinne Heyning

"Cigarette lighter, plastic bottle cap, tooth brush, plastic action figure leg," Dr. Marcus Eriksen said, naming, in rapid fire staccato, the pieces of trash dangling from a plastic rope fragment he held up. "Everything you see here I pulled out of a bird's skeleton at Midway Atoll, an island about 2000 miles away from here out in the middle of the ocean." As he spoke, the fifty or so kids standing on the banks of the Los Angeles River gawked at him, their slack jaws and wide eyes giving voice to their thoughts: *"You found all that inside a bird?"*

"What can you do about it?" Eriksen asked, his tone and intent gaze not letting up for an instant.

"Recycle," one seventh grader suggested quietly.

"Don't litter," another added.

Eriksen lifted his brows. "That's good, but how about," he paused dramatically, "Refuse?" The group's quizzical look made him smile. "Bring your own bottle. Bring your own bag," he explained. "Refuse to use plastic. Change. Today. Be a leader. We can change the world," he said to the kids, who were by now cheering. "Go down there and clean the river," he told them as they strode past him to do just that.

At least a dozen times that overcast October morning,

Continued on page 7

Letter from the Top

line-up

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and Key Personnel

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John M. Fentis
President, Algalita Marine Research Foundation

Dear Friends of AMRF,

I would like to share some significant events that contributed to the continued growth and well-being of the Algalita Marine Research Foundation in 2007. In June our work was recognized by Mrs. Laura Bush after she visited the Hawaiian Islands National Monument and expressed concern about the amounts of plastic accumulated there. Our efforts were instrumental in getting Assembly Bill 258, aka "The Nurdle Bill," passed and signed into law. This bill improves the handling of pre-production plastic pellets, or nurdles. In October our Founder, Captain Charles Moore, completed a fifth voyage to the North Pacific Gyre to collect scientific data on plastic in the ocean. School children throughout the world participated in the trip via satellite communication just as they will in the upcoming year-long circumnavigation of the Gyre. Newspaper articles and television interviews detailing the work of AMRF brought the issue of plastic and marine debris to unprecedented levels of public awareness. Our list of volunteer workers continues to grow, and there are plans to expand our research and educational outreach programs to new regions of the United States and Mexico.

In a perfect world our waters would be pure, our manufacturers would be conscientious and our neighbors would be careful with their waste. In a perfect world, AMRF's work would not be necessary. Unfortunately, this is not the case. Water samples collected on the last voyage show that increasing amounts of plastic pollute our seas and industry embraces the notion that the problem can be cured by increased recycling efforts. Additionally, industry has resisted in participating in meaningful research that would lead to a better understanding of plastics' effects on the environment, and legislative efforts restricting the use of plastic bags and polystyrene packaging has been met with opposition by commercial interests.

All of this indicates that we are still in the beginning stages of confronting this highly-charged environmental issue. There is a mountain of education and research yet to climb before we can achieve some meaningful clarity.

I recently visited New Zealand where I happily trekked over miles of pristine beech forests laced with lush ferns and carpeted with endless varieties of moss. I was grateful to be in a paradise where one could fill a container with crystal clear water from a stream and drink it without purifying it first. Near the end of my trip, I visited friends on the Awhitu Peninsula about 60 miles from Auckland. There is one road which provides vehicular access to the Tasman Sea and the entrance to Manukau Harbor, one of two harbors which bless Auckland. As I strolled the black sand beach, I was saddened to see bottles, plastic lighters, plastic containers and packaging blighting the landscape.

The message is clear: plastic is everyone's problem...not only those who use it but those who manufacture it. While the prospect of correcting the damage that has already been done is dim, the obligation to prevent and curtail further damage is paramount. It is a problem that can be addressed only if we shed our preconceived posturing and make a firm commitment to resolve the dangers that face our marine environment and the human race.

MISSION STATEMENT | ALGALITA MARINE RESEARCH FOUNDATION

The Algalita Marine Research Foundation is dedicated to the protection of the marine environment and its watersheds through research, education and restoration.

Laura Bush Delivers the Mermaid's Purse

By Corinne Heyning

Last June when the AMRF Board of Directors gathered for a board meeting, everything appeared to run as usual. Role and agenda were called. Committees briefly met. The room buzzed with private conversations and lengthy discussions about the organization's successes and challenges. In the midst of it all, the morning mail arrived.

No one noticed except Marieta Francis, AMRF Director of Operations, who shuffled through the mail selecting one piece, a letter from the White House, to hold up high. For a few moments, as someone read the short note, breaths were held. Silence reigned. But with the reading of the salutation, quiet gave way to wide grins, back slapping, hand shaking and loud rounds of congratulations. Elated staff and board members began planning for the future. "Everyone was so excited," Marieta recalls. "Laura Bush responded to our letter!"

The plastic debris this Laysan Albatross ingested contributed to its death and will remain long after its skeleton disintegrates.

The impetus for AMRF's writing to First Lady Laura Bush came in March, 2006 after her speech commemorating the Northwestern Hawaiian Islands Marine National Monument. In that speech, Mrs. Bush made pointed mention of many of the issues AMRF has been studying for years: the abysmal plight of the Laysan Albatross and other marine life due to plastic pollution, the spoiling of once pristine shorelines from trash washing ashore far from its point of origin, and the role each of us plays in solving the problem.

"The First Lady recognizes that marine plastics are a problem and it is part of our mission to make everyone aware of it," Board President, John Fentis said recently. Capitalizing on the statements Mrs. Bush made while in Hawaii, AMRF wrote to the First Lady. In part, our letter intended to further her education about the toxic threat plastics pose for humans, and in part it sought to find a way through the maze of federal grant-giving. Addressing the latter point, we asked the First Lady to direct us to the individuals and institutions charged with funding research designed to determine the biological impacts of plastics upon wildlife and humans.

Like a bejeweled mermaid's purse, or shark egg, sleek on its exterior and endowed with all the life sustaining nutrients the little shark needs to survive, her response surprised and delighted the board and staff. Not only did Mrs. Bush share our mailing with her Projects Office, but also with James Connaughton, Chairman of the Council on Environmental Quality. In addition, she implicitly gave her consent for AMRF to contact Connaughton, President Bush's Senior Environmental & Natural Resources Advisor and Director of the White House Office of Environmental Policy.

Unbeknownst to the First Lady, AMRF had already written to James Connaughton as well as to other prominent officials at the National Oceanic and Atmospheric Administration (NOAA), the Department of the Interior, the Department of Commerce and high-ranking individuals in the Hawaiian state government. Each letter requested assistance for securing funding to carry out our research and education programs.

The letter-writing campaign has begun to pay dividends. Since writing Mrs. Bush in March 2006, AMRF has made significant inroads beyond the outer banks of the Beltway: NOAA's Sanctuary Coordinator for Northwestern Hawaiian Islands Coral Reef Ecosystem, Sean Corson, personally called the AMRF office with an interest in our research; Linda Lingle, Governor of Hawaii, wrote providing us with contact personnel; the Regional Director of the US Department of the Interior, Fish and Wildlife Service, directed us to contact Andrew Gude who, in turn, provided us with a whole new list of names and contacts for funding and information.

That each of these leads is significant as possible future funding sources is not lost on Marieta, who is following up on the letters, phone calls and emails as fast as they accumulate. The dialogue with Washington has begun and will continue. Just how high up the political food chain we will need to go is anyone's guess, but given our success to date, we feel confident that we will get results.

The Grommet Dictionary

*The **Grommet Dictionary** is an occasional column in* **Flotsam and Jetsam**. *It represents an effort on our part to ensure that we all speak the same language, for if we do not, we run the risk of not talking to one another at all.*

The name of this column is Grommet Dictionary. In the lexicon of surfers, a grommet is a young, upstart surfer, sometimes even a hot shot. Of course, grommet also means "eyelet," for which one of the definitions is an eyehole in a wall.

Thus, both meanings – young upstart and eyehole – are appropriate, and symbolic, to AMRF. We were founded over 13 years ago, the upstart bucking the norm, drawing attention to what others chose not to see. Though we have grown and are considered a leader in an, as of yet, undiscovered field, the need for us to continue to concentrate our efforts on the problem of plastic in the worlds' waterways and to rattle the establishment is ever more pressing.

Moreover, we want the world to see and know what plastic is doing to our oceans. We want to be that window of consciousness, the eye of the water.

Corinne Heyning
Newsletter Editor

Absorb

To suck up or drink in (a liquid); soak up: A sponge absorbs water. To take up or receive by chemical or molecular actions.

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currents

Plastic In the News

Coca-Cola and FedExKinkos Invest in Recycling

Synopsized by Cathy Cressy-Torrones

The Zero Waste movement won a new supporter as the Coca-Cola Company set long-term goals to have every bottle it sells in the U.S. recycled or reused. Coke's plans to increase recycled polyethylene terephthalate (PET) content in its plastic bottles, from current 10% content to 30% by 2010, did not include a target date for its 100% goal.

In conjunction with the private firm United Resource Recovery Corp., Coca-Cola plans to build the world's largest plastic bottle-to-bottle recycling plant. The plant will produce, in food-grade recycled PET, the equivalent of two billion 20-ounce Coke bottles for reuse each year.

Coca Cola is also expanding its investment with Recycle Bank, a for-profit company that uses discount coupons from Starbucks and Whole Foods to reward people for recycling. The program is currently available in three east coast states, but a national rollout is planned for 2009.

In other news from the Zero Waste movement, Forest Ethics and Dogwood Alliance in their "report card" on paper practices gave Staples and FedExKinkos high marks.

Staples achieved an A grade with its 30% average of post-consumer recycled content stating it wants to increase that statistic to 50%. FedExKinkos also meets or exceeds ambitious goals, achieving a B+ grade. Office Max and Corporate Express are the industry laggards in recycling.

Adapted from the online website marcgunther.com (Sept. 5, 2007); www.marcgunther.com

The Nurdle Hurdle

By Corinne Heyning

Your 3rd grader is learning to use the dictionary. Her assignment this week includes looking up the word "nurdle." "I can't find it," she pouts.

"Sure you can. I'll help you," you say, sitting down confidently to show her how it's done. Only, you can't. "I encountered the word in literature, but couldn't find it in the dictionary," says Tamara Adkins, doctoral student in Environmental Studies at Antioch University New England. Online dictionaries, such as *Double-Tongued* and *Urban Dictionary*, contain some very amusing definitions of "nurdle," but not the one she was looking for. And, although *Wikipedia*, an online encyclopedia, makes a good attempt at getting to the meaning of the word as we at AMRF know it, it didn't feel very official to her. Specifically, "There was nothing in the *Oxford English Dictionary*," and nothing in *Merriam-Webster's* either."

As a result, Ms. Adkins made it her goal, and part of her grade, to rectify that situation.

Choosing the gold-standard of dictionaries, the *Oxford English Dictionary* (OED), as her recipient of nurdle, she set about submitting it. "I have to say that OED's submission procedure is daunting, but I got through it," she said, after successfully submitting it to OED as a noun defined as a pre-production plastic pellet. Bolstering her submission were citations of how the word is used in common written language as well as in California AB 258, a California bill that set up a task force to monitor and regulate the discharge of preproduction plastic pellets into the marine environment.

Nurdles, like these, may be found on beaches the world over.

Because OED wants the etymology, or history, of word origins, not just the definition, Ms. Adkins also contacted Algalita, arguably the world's authority on nurdles. Algalita's founder, Captain Charles Moore, responded to her request while at sea.

He explained that the term nurdle was coined by the Huntington Beach junior lifeguards in the 1970s. As the kids sat on the beach awaiting their turns to paddle or swim, they sifted sand through their fingers finding and collecting piles of plastic pellets they dubbed "nurdles."

Like, duh? Who, but a kid, would come up with a word like nurdle?

Ms. Adkins relayed Captain Moore's etymology of nurdle to OED who responded, writing: *"Your earlier helpful message is already in our files, and I shall add this information to it. It will be of great assistance to our team of etymologists when they come to work on NURDLE. We are most grateful."*

Well done, Ms. Adkins. Looks like "nurdle" might just be poised for elevation in the world's consciousness, and at Algalita we think you've earned A+.

Junior lifeguards coined the word "nurdle" after discovering them on Southern California beaches in the 1970s.

AMRF Scours the Seas

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"It's a desert of death," said ship doctor Joseph Goodman. "Nothing is moving in the water. Everything is dead. It's very disheartening. Very scary," he said about the way plastic is choking the life out of the ocean.

But as destructive as the exponential increase in the quantity of plastic found in the sea is, it is its ability to attract and hold pollutants that makes it exceedingly dangerous. Captain Moore describes the garbage patch as a toxic stew, a contaminated "floating landfill."

Despite the image this description conjures, the Garbage Patch is not a solid island of floating trash. Rather, it consists primarily (but not exclusively) of pieces of plastic and other junk both floating and submerged deep beneath the surface. This makes it qualitatively quite different from the way the Los Angeles River looks after a rain storm.

Captain Moore explains that pesticides, polychlorinated biphenyls (PCBs) and polyaromatics (collectively known as persistent organic pollutants, or POPs) permanently attach themselves to plastic as they circulate around the surface of the Pacific gyre. During this journey, plastic photodegrades, but does not biodegrade. This means that over time, the sun's UV rays break plastic into small pieces, or even into plastic dust.

As a result of this process, "there is a new sediment layer forming. A liquid layer of plastic," said Captain Moore. This "sludge" layer is trouble. Treble trouble. Not only does it threaten sea life because it fills animals' bellies and causes starvation, but it is toxic (studies have shown that a female dolphin's first offspring frequently dies from toxicity when the mother "dumps" her toxins into her milk), and it is impossible to clean up. After all, how do you scoop soup out of the sea?

"Animals are the ocean's vacuum cleaner," Dr. Lorena Rios said. "Everything that floats in the ocean is food. The albatross fly in and take the plastic. They don't know what it is," or what toxins it contains, but that doesn't keep jellyfish, turtles, birds and fish from eating the red, blue and green caustic bits of trash.

"This is the problem," Dr. Rios said, explaining that toxins concentrate up the food chain. Eventually, perhaps even now, the seafood humans consume will contain POPs.

It will take Dr. Rios approximately nine months to complete her analysis of all the water samples collected on the voyage. Once completed, she hopes to determine not only what types of contaminants are on the plastic, but to pinpoint the source of the poisons adhering to it.

Captain Moore and others on the trip remarked that they saw Chinese and Japanese writing on some of the

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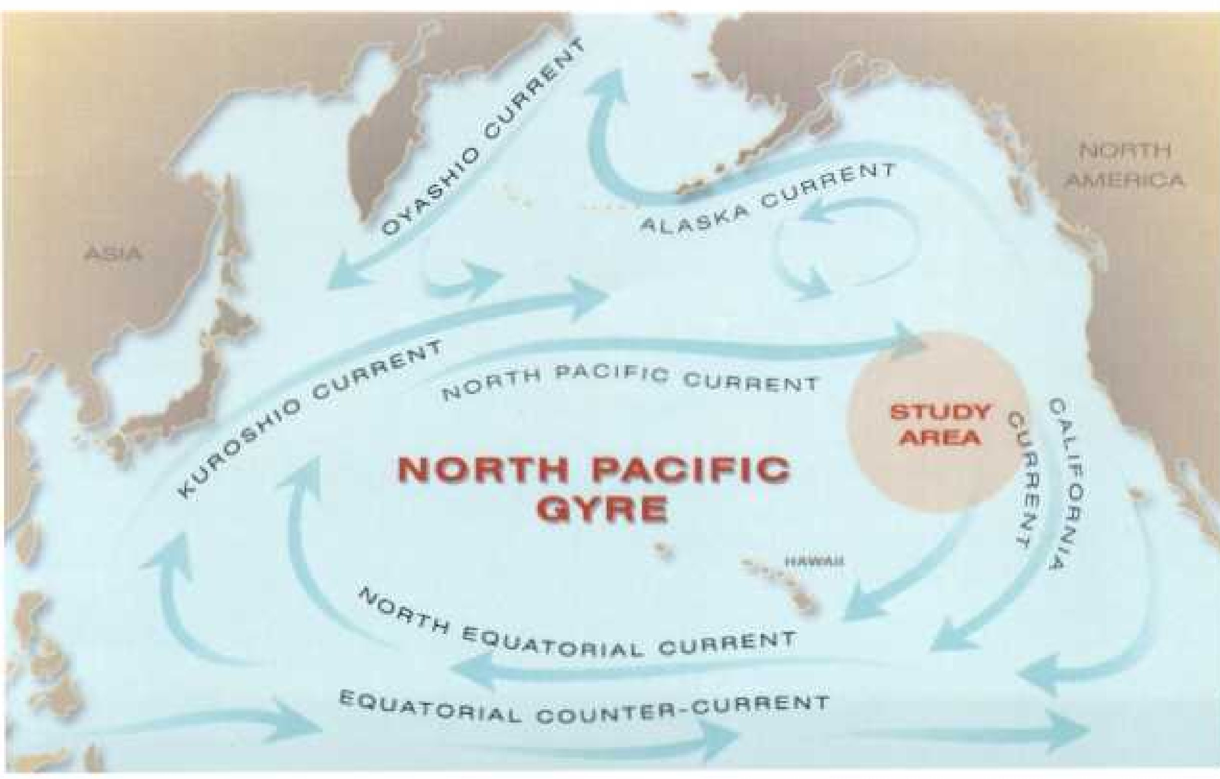

The Grommet Dictionary

Adsorb

To gather (a gas, liquid, or dissolved substance) on a surface in a condensed layer: Plastic adsorbs pollutants.

Cradle-to-cradle

The notion that products should not be thought of as having only one use, rather that they are continually recyclable and in this way can be used many times. Implementation of this concept is how the problem of pollution will ultimately be solved.

Ghostnet

A fishing net, regardless of its material (rope or plastic), that is discarded into the sea either having been lost by accident or purposefully cut loose. It is "unmanned," no longer hauling in a catch for human consumption yet continues to "fish," catching and killing unintended prey: fish, mammals, reptiles, birds and invertebrates.

Gyre

A swirling vortex caused by winds or ocean currents. In the Northern Hemisphere, the gyre rotates clockwise; in the Southern Hemisphere it rotates counterclockwise. The North Pacific Gyre, which ocean researcher Charles Moore has been studying, is located between the equator and 50° latitude. It is approximately ten million square miles and its circular pattern comprises four ocean currents: the North Pacific current to the north, the California Current to the east, the North Equatorial Current to the south, and the Kuroshio Current to the west.

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Dr. Julie Bolton Dishes It Up at the Long Beach Farmer's Market

Doctor's environmental concerns prompt her to educate others

VOLUNTEER SPOTLIGHT

"What's that? Why's it here?" an inquisitive 10 year old asked as he thrust his hand into a pile of plastic bits selecting, as if by instinct, the flat, black L-shaped skin of a toy gun.

A woman wearing mirrored aviator glasses and a warm jacket smiled. "Boys always seem to pick that up first," she said, explaining that all the plastic in the tub came from Kamilo Beach, Hawaii. "There's no more sand on that beach. It's all colored bits of plastic. Look at this. What does this tell you?" she asked, selecting from the bin a toothbrush with black Asian script on its handle.

Over and over that morning little vignettes such as this played out for Julie Bolton, family physician and AMRF volunteer, who for the for the last year has set up an education table at the Long Beach Farmers Market one Sunday a month. Julie undertook this project on her own initiative after meeting Marieta Francis in AMRF's offices while on a stroll. She read the *Plastics are Forever!* brochure and was shocked by what she learned.

"I thought that recycling household plastic was enough, but then I learned the truth," she said. So after modifying her own consumer behaviors she began monthly forays to the Farmers Market to spread the message. "You don't need to be part of the problem. You can be part of the solution," she said.

And what a great solution. Even the late January cold and intermittent rain didn't impede Julie's quest to get the message out as a continual stream of folks stopped by her table. Families with small children picked up plastic junk. Couples examined the biodegradable tableware and cutlery she displayed. Some folks looked at the photos of dead albatross or the drawing of the gyre.

Julie is definitely getting the message out, but in the process she's enjoying herself, too. "This is a really fun thing to do," she says. "People don't get hostile. You are just informing them and everyone has a story to tell." Seemingly to prove her point, a man stops at the table. He picks up the nurdle jar, "I used to find these on the beach when I went surfing as a kid," he says.

Julie nods knowingly. "I'd love to see more volunteers go to farmers markets. That would be great."

With Julie as an example, that would be great for the volunteers and for AMRF.

AMRF Scours the Seas

Continued from page 5

larger plastic trash they collected, but Captain Moore is fairly certain that a fair share of the trash originates in California as well.

As significant as Dr. Rios' research is to the ongoing mission of AMRF, the ORV *Alguita's* most recent voyage is also noteworthy in that it elevated public awareness of the problem plastic trash in the ocean has become.

This voyage marked the first time that the ORV Alguita went live on the internet with daily BLOG updates from Captain and crew (http://orvalguitablogspot.com). This allowed thousands of people to sail with AMRF as crew members picked up old tires and ghost nets from the ocean.

In addition, Holly Gray, Vessel Support Coordinator, successfully arranged for school children from around the globe – Australia, Canada, Japan, Puerto Rico, Guam, Chili, Columbia, Pakistan, Germany and the U.S. – to not only participate in the voyage via the web, but to ask the crew questions in realtime. A total of 23 schools and 1000 students were involved in the orvalguita.googlepages.com web site.

Captain Moore is also hopeful that the inclusion of the documentary film crew from VBS TV will help cultivate a younger and different audience than the one environmental news typically reaches. "Our youth are going to have to live with the problem that plastics are creating," said Captain Moore, stressing that it is important to educate them and to help them find solutions.

On September 30th, three weeks after leaving home port, the ORV Alguita arrived in Hilo, Hawaii. It didn't take long for the news to spread: Plastic is killing our seas. *NPR, The San Francisco Chronicle, Honolulu Star Bulletin, The Today Show* as well as other well-recognized news media began covering the story.

For a decade Captain Moore has said, "We sweat the small stuff." Finally, it appears that people are listening.

currents

Plastic In the News

West Coast Governors on Ocean Health

Synopsized by Cathy Cressy-Torrones

In a press release dated October 26th, 2007, The Joint Ocean Commission Initiative applauded West Coast governors for the release of a draft action plan to further the implementation of the West Coast Governors Agreement on Ocean Health. "This was a landmark agreement by the governors," said Leon E. Panetta, co-chair of the Joint Initiative. "This draft action plan clearly identifies priorities and outlines specific actions that are responsive to the protection and preservation of our ocean's health."

In September 2006 the three West Coast governors entered into an agreement identifying issues that could be more effectively addressed if the states collaborated. The plan addresses implementing ecosystem-based management, preparing for the effects of climate change, addressing polluted runoff, supporting research needs; and establishing a national ocean trust fund that would provide sustained funding for ocean and coastal management.

More information can be found at www.jointoceancommission.org

L.A.River

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Eriksen repeated his message to subsets of the 550 middle school and high school children from throughout Los Angeles who attended the Friends of the Los Angeles River (FOLAR) River School clean up. The kids were attracted to AMRF's booth by the odd assortment of trash Eriksen carts around with him. On that Friday morning, he displayed the trash "necklace," a bottle of ocean water flecked with chunks of semi-broken down plastic which had discolored to a disgusting cream color, homemade and purchased cloth grocery bags and the plastic-bottle Cola Kayak that students at the Environmental Charter High School in Lawndale had helped construct.

Besides AMRF and FOLAR, Heal the Bay, El Dorado Nature Center and the Tidepool Cruiser from Windows-On-Our-Waters attended the clean up event. Alicia Katano, FOLAR event organizer, said that of the nearly 5,300 pounds of trash collected that morning, Styrofoam and plastic were by far the most prevalent items picked up. FOLAR would have liked to have conducted a true trash sort, but concerns over contamination prevented it. "We were thrilled that everyone came out and that we partnered with Algalita," she said, adding that the seven middle and high schools attending the clean-up represented a wide geographic area within Los Angeles.

Leland King, a 7th grader at Brentwood School, stood high on the river's embankment watching the activity below. "You gotta clean up. Don't drink out of plastic bottles. Recycle," he said. "That's a new idea to me."

While Eriksen and his colleagues at Algalita stress the importance of recycling, Eriksen says that this is only part of the story. Ideally, people need to rethink the entire trash cycle, beginning with packaging and eliminating one-time-use articles from their repertoire of activities. Still, he says, "If we reach 10% of the kids with a recycle message, it's a start, and that makes the day a success."

"Refuse to use plastic," Dr. Eriksen tells a group of students while standing next to the Cola Kayak.

The Grommet Dictionary

Mermaid's Purse

The horny or leathery egg case of certain cartilaginous fishes, such as skates and sharks.

See article page 3

Nurdle

Pre-production plastic pellets.

See "The Nurdle Hurdle," page 4

Zero Waste

A concept that there should be no waste in the world. Within a zero waste framework, items left over from production or after use are considered "residual product," or potential resources.

See "Currents," page 4

*Unless otherwise noted, **Grommet Dictionary** gives an environmental slant on a word's meaning.*

Eco-tips Reduce. Reuse. Recycle.

- **Bring your own cloth grocery bags** to the store. If you forget, at least be ECO-nomical: use paper grocery bags. Bring them back. Some stores will give you a discount on your next grocery tab.
- **Forget the hose.** Sweep driveways and patios to keep litter, leaves and debris out of street gutters and storm drains. Dispose of debris securely in trash cans.
- **Start a compost heap** and toss the coffee filter and grounds along with egg shells and vegetable peelings.
- **Reuse whenever possible**... like that plastic bread bag. Give it another life as a sandwich bag in your child's lunchbox.
- **Refuse to buy excessively packaged products** and choose products packaged in recycled materials.
- **Use environmentally friendly cleaning products** that are low in phosphorous. You'll reduce the amount of nutrients discharged into our lakes, streams and coastal waters, get your stuff clean and feel good about yourself on top of it.
- **Be a class act. Impress someone with your silverware and china.**
- **Want to know how long things take to biodegrade?** According to the History Channel: *banana peel* – 3 weeks; *newspaper* – 1 month; *cotton rag* – 5 months; *wool sock* – 1 year; *tin can* – 100 years; *aluminum can* – between 200 & 500 years; *plastic jug* – 1 million years; *Styrofoam cup* – possibly never.
- **Refuse** \ri-fyüz\ *verb.* **Refuse** \re-fyüs, – fyüz\ *noun.* Think about it.

"The only solution is to do no more harm."

Marcus Eriksen, PhD, *Director AMRF Research and Education*

Oceangoing Research Vessel
ORV Alguita

ALGALITA MARINE RESEARCH FOUNDATION
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inside

* Manuscript

Synthetic Polymers in the Marine Environment: A Rapidly Increasing, Long Term Threat

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ABSTRACT

Synthetic polymers, commonly known as plastics, have been entering the marine environment in quantities paralleling their level of production over the last half century. However, during the last decade of the 20th Century, the deposition rate accelerated exponentially, and they are now one of the most common and persistent pollutants in ocean waters and beaches the world over. Thirty years ago the prevailing attitude of the industry was that "plastic litter is a very small proportion of all litter and causes no harm to the environment except as an eyesore" (Derraik, 2002). Between 1960 and 2000, the world production of plastic resins increased 25 fold, while recovery of the material remained below 5%. Between 1970 and 2003, plastics became the fastest growing segment of the US municipal waste stream, increasing nine-fold, and marine litter is now 60-80% plastic, reaching 90-95% in some areas. While undoubtedly still an eyesore, plastic debris today is having significant harmful effects on marine biota. Albatross, fulmars, shearwaters and petrels mistake floating plastics for food and few individuals of these species remain unaffected; in fact, 44% of all seabird species ingest plastic. Sea turtles ingest plastic bags, fishing line and other plastics, as do 26 species of cetaceans. In all, 267 species worldwide are known to have been affected, a number which will increase as smaller organisms are assessed. The numbers of fish, birds, and mammals that succumb each year to derelict fishing nets and lines in which they become entangled cannot be reliably known, but estimates in the millions have been made. We divide marine plastic debris into two categories; macro, >5mm and micro, <5mm. While macro debris may sometimes be traced to its origin by object identification or markings, micro debris, consisting of particles of two main varieties, degraded pieces broken from larger objects, and resin pellets and powders, the basic thermoplastic industry feedstocks, are difficult to trace. Ingestion of small plastics by filter feeders at the base of the food pyramid is known to occur, but has not been quantified. Ready ingestion of degraded plastic pellets and fragments raises toxicity concerns since they are known to sorb hydrophobic pollutants. The potential bioavailability of compounds added to plastics at the time of manufacture, as well as those sorbed from the environment is a complex issue that merits more widespread investigation. The physiological effects of any bioavailable compounds desorbed from plastics by marine biota are beginning to be directly investigated, since Ryan et al. found that the mass of ingested plastic in Great shearwaters was positively correlated with PCBs in their fat and eggs. Colonization of plastic marine debris by alien species poses one of the greatest threats to global marine biodiversity. There is also potential danger to marine ecosystems from the accumulation of plastic debris on the sea floor. The accumulation of such debris can inhibit gas exchange between the overlying waters and the pore waters of the sediments, and disrupt or smother inhabitants of the benthos. The extent of this problem and its effects have recently begun to be investigated, and based on resin sales in the United States, a little more than half of all thermoplastics will sink in seawater.

KEYWORDS: Marine Debris, Plastic Debris, Persistent Organic Pollutants, Microplastic Pollution, Xenoestrogens

Outline

1. INTRODUCTION

A major unforeseen consequence of the "Plastic Age" is the material's ability to proliferate in infinite configurations throughout the marine environment worldwide (Moore, 2003). The physical characteristics of most plastics show high resistance to aging and minimal biological degradation. When exposed to the UVB radiation in sunlight, the oxidative properties of the atmosphere and the hydrolytic properties of seawater, these polymers become embrittled, and break into smaller and smaller pieces, eventually becoming individual polymer molecules, which must undergo further degradation before becoming bioavailable. The eventual biodegradation of plastics in the marine environment consumes an unknown amount of time, but estimates on the order of centuries have been made (Andrady, 2000), contributing to the fact that plastics are accumulating in exponentially increasing quantities in the marine environment (Copello, 2003, Ogi, 1999). Slow biodegradation rates do not mean that plastic polymers and their additives are not bioactive. The process of polymerization of the monomers that form plastics is never 100% complete, and the remaining monomer building blocks of the polymer, such as styrene and bisphenol A, along with residual catalysts, can migrate from the polymer matrix into compounds with which they come in contact. Polycarbonate plastics, when exposed to the salts in seawater, show accelerated leaching of bioactive bisphenol A monomer (Sajiki, 2003). Many plastic polymers in commercial use have high concentrations of bioactive monomer additives, such as UV stabilizers, softeners, flame retardants, non stick compounds, and colorants, which leach out at faster or slower rates based on environmental conditions. Colton (1974) estimated that plastic products average about 50% of these compounds by weight.

While it is beyond the scope of this paper to delve into the intricacies of polymerization, and the production of thermoset and thermoplastic resins, the leaching of some bioactive substances from commercial plastics will be covered by other papers in this series. Briefly, thermoplastics are the main type of consumer plastics and are formed by melting the plastic raw material and forming it into products, which can be recovered and re-melted. They are distinguished from thermoset plastics, liquids which are "set" by the use of a catalyst and scorch rather than re-melt when exposed to heat. Thermoset plastics also break into small bits and persist in the environment, and though produced in less quantity than thermoplastics, are recovered or recycled at an even lower rate.

The modern trend is for nearly all consumer goods to contain and/or be contained by plastic, and recovery of the material does not provide readily realizable profits, or options for reuse (Unnithan, 1998), therefore plastics are the fastest growing component of waste. Some of this waste makes it to disposal sites, but much of it litters the landscape. Since the ocean is downhill from virtually everywhere humans live, and about half live within 50 miles of the ocean, lightweight plastic trash, lacking significant recovery infrastructure, blows and runs off into the sea. There, it moves to innumerable environmental niches, where it causes at least eight complex problems, none of which are well understood. 1) Plastic trash fouls beaches worldwide, devaluing the experience of beachgoers. Medical waste, plastic diapers and sanitary waste often found among this debris constitutes a public health hazard. 2) Plastic entangles marine life and kills through drowning, strangulation, and drag on feeding efficiency. So called "ghost nets" continue to fish after being lost or abandoned by their owners and kill untold numbers of commercial species. 3) Ingestion of plastic items that mimic natural food fails to provide nutrition proportionate to its weight or volume. It kills seabirds through starvation and false feelings of satiation, irritation of the stomach lining, and failure to put on fat stores necessary for migration and reproduction. Sea turtles and marine mammals with ingested plastic have been found washed up or floating dead, but linking mortality unequivocally to the ingested debris is difficult. 4) Petroleum-based plastic polymers do not biodegrade, and are long-lived and slow moving in the ocean. As such, they are hosts for "bryozoans, barnacles, polychaete worms, hydroids and mollusks (in order of abundance)," and may present a more effective invasive species dispersal mechanism than ship hulls or ballast water (Barnes, 2005). 5) Plastic resin pellets and fragments of plastic broken from larger objects are sources and sinks for xenoestrogens and persistent organic pollutants (POPs) in the marine and aquatic environments (Moore, 2005, Mato, 2001, Rios, ~~In Press~~), and are readily ingested by invertebrates at the base of the food pyramid (Andrady, 2005, Thompson, 2004). 6) Since the majority of consumer plastics are neutrally buoyant (within 0.1g/mL of seawater density, USEPA, 1992), grains of sand caught in their seams or fouling matter make many plastics sink to the sea floor. Much of this material consists of thin packaging film and has the potential to inhibit gas exchange, possibly interfering with CO_2 sequestration (Goldberg, 1997). It also has the potential to interfere with or smother inhabitants of the benthos. 7) Marine litter threatens coastal species by filling up and destroying nursery habitat where new life would otherwise emerge (UNEP). 8) Marine plastic litter fouls vessel intake ports, keels and propellers, and puts crewman at risk while working to free the debris; incurring significant damage and economic costs for vessels (6.6 billion Yen/yr. in Japanese fishing vessels <1000 gross tons, Takehama, 1990).

Given the variety of problems caused by plastic debris, it is important to gauge its rate of change. In the early 1970s, a study in the Atlantic of 247 surface plankton samples from Cape Cod to the Caribbean found plastic in 62% of samples. A similar study in the Pacific during the mid 1980s of 203 samples from the Japan to the Bearing Seas and north of Hawaii found plastic in 59% (Colton, 1974, Day, 1990). From the 1960s to the 1990s evidence from archived plankton samples off Great Britain suggests that marine plastics increased at a rate approximating their steadily increasing production (Thompson, 2004). Then, during the decade of the 1990's, plastics in the US municipal waste stream tripled (USEPA, 2003) and researchers found accelerating levels in the marine environment. I found plastic in all trawl samples in studies from 1999 to 2007 in the north Pacific, with maximum neuston (surface) plastic levels three times greater than Day had found a decade earlier (Moore, 2001). From 1994 to 1998, debris levels around the United Kingdom coastline doubled, "and in parts of the Southern Ocean it increased 100-fold during the early 1990s" (Barnes, 2002). Ogi (1999) found that neuston plastic increased 10-fold in coastal areas of Japan during the 1970s to 1980s, but that during the 1990s, densities increased 10-fold every two to three years. The most extreme rate of change is at polar latitudes, threatening to turn the pristine shores of Antarctica into a wasteland (Barnes, 2002).

Once it reaches the ocean, plastic debris is dispersed in various ways. Onshore winds force land-based debris entering the ocean from rivers and storm drains back to the shore, while offshore winds push debris towards major ocean current transport systems. Both types of wind have greater effect on objects that have appendages above the sea surface. In the deep ocean, large high-pressure systems known as gyres tend to accrete the debris, while low-pressure systems tend to disperse it (Ingraham, 2000). In the largest gyre, located in the central North Pacific, neuston trawls for plastic debris yielded the astounding figure of six kilos of plastic fragments for every kilo of zooplankton >0.333mm in size (Moore, 2001) (Fig. 1).

2. PLASTIC DEBRIS CONCERNS

It was inevitable that a lightweight product filling so many commodity niches, which does not biodegrade, and is often used only once and discarded, would eventually cause problems for the marine and terrestrial environments where it accumulates.

2.1 Aesthetics

According to the World Health Organization, a clean beach is one of the most important characteristics sought by visitors. The negative effects of debris, defined as solid materials of human origin, are: loss of tourist days; resultant damage to leisure/tourism infrastructure; damage to commercial activities dependent on tourism; damage to fishery activities; and damage to the local, national and international image of a resort. "Such effects were experienced in New Jersey, USA in 1987 and Long Island, USA in 1988 where the reporting of medical waste, such as syringes, vials and plastic catheters, along the coastline resulted in an estimated loss of between 121 and 327 million user days at the beach and between US$ 1.3×10^9 and US$ 5.4×10^9 in tourism related expenditure" (WHO, Bartram, 2000). Naturally clean beaches, free from debris, are a thing of the past. In the 20 years since the Ocean Conservancy organized the first annual International Coastal Cleanup Day, 6 million volunteers from 100 countries have removed 100 million pounds of litter from 170,000 miles of beaches and inland waterways. Reports of groups finding nothing to pick up do not exist. While the International Cleanup Day effort expands each year, so does the amount of debris recovered. Between 1996 and 2006, at Escondido Beach, California, 310 total debris items were removed, but 182 of those were found in 2005, representing 59% of the total recovered in the last year of the 10-year effort. At Torrey Pines State Beach, California, in all four quarters of 2005, 136 items were removed, but in the second quarter of 2006 alone, 189 items were found (Ocean Conservancy).

It must be remembered that beach cleanups focus on macro debris. Numerous studies have found micro debris in beaches worldwide, many of them remote from human activity. (McDermid, 2004, S.Moore, 2001, Gregory 1977-1999, Thompson, 2004, Ng, 2005). In a study of a beach, near an urban river mouth, we found the sand to be 1% plastic by volume down to a depth of 20 cm. (unpublished data). Whether, or to what extent, mixing lighter plastics with heavier sediments by raking up the macro debris contributes to beach erosion has not been determined. Mechanical raking and grooming of beaches to remove debris tills in plastic fragments and may also contribute to erosion by removing plant roots and seaweed that anchor sand.

Floating debris is an aesthetic issue for swimmers, mariners, coastal and inland water body dwellers, and submerged debris is an aesthetic issue for divers.

2.2 Entanglement

In the 1980s, researchers estimated that there were 100,000 marine mammal deaths per year in the North Pacific related to entanglement in plastic nets and fishing line (Wallace, 1985). Currently NOAA is using digitally enhanced photos of wounds suffered by marine mammals to identify the type of line they were entangled in. Lost and abandoned nets, termed "ghost nets," continue to fish and destroy resources. A report by Canada's Food and Agriculture Organization (FAO, 1991) estimates that 10% of all static fishing gear is lost and that this results in a loss of 10% of the target population. Efforts to remove this gear are growing, but are not widespread, and the great cost of removal of derelict gear is rarely, if ever, borne by those who manufacture it or lose it. Indeed, if it were, it could threaten the economic viability of commercial fishing. Documentation of entanglement of seabirds and other marine species in 6-pack rings used to hold cans and bottles has resulted in changes to the plastic formula to speed up disintegration in the environment. The polymer can be changed chemically during manufacture so that it absorbs UV-B radiation from sunlight and breaks down into a very brittle material in a fairly short period of time, however, the resulting particles are no more biodegradable than the untreated polymer (Andrady, 2005). Such embrittlement accelerators are not used in nets and lines, however, and volunteer groups worldwide are regularly called on to free entangled cetaceans and other sea life.

2.3 Ingestion

The term "plastic" means "capable of being formed into any shape." The plastic objects that populate the marine and aquatic environments, with the exception of fishing lures, are not made to look like natural food to marine creatures, though thin plastic shopping bags balloon out in water to appear like jellyfish and are regularly consumed by sea turtles. It seems probable that the infinite ways in which the mega-tons of multi-colored plastic debris break down in the marine environment create mimics for virtually every natural food source. Andrady (2005) reported on feeding studies by Alldredge at UC Santa Barbara, using Ivlev's Electivity Index (designed to quantify prey-selection by predators, especially planktivores), showing that two common species, *Euphausia pacifica,* and *Calanus pacificus* had values of the index very close to zero and that ingestion of contaminant free, uncolonized plastic particles, versus natural prey, appeared to be non preferential. Most feeding that takes place in the ocean is accomplished by indiscriminate feeders with mucus bodies or appendages designed to adhere to and capture anything of an appropriate size with which the organism comes in contact. Collection of salps in the North Pacific Central Gyre by Algalita Marine Research Foundation (AMRF), using both plankton trawls and hand nets, found individuals with plastic particles and fishing line embedded in their tissue. The optimum size class of plastic for filter feeder ingestion appears to be around 1 mm in diameter, although individuals with larger particles have been found. A 1999 AMRF study of 27,448 plastic particles trawled from the surface of the Gyre found 9,470 particles near 1 mm in size, 4,646 near 0.5 mm, and 2,626 near 0.3 mm, suggesting that smaller particles are being removed, or are leaving the system by some unknown mechanism (Moore, 2001). Thompson (2004) kept inter-tidal invertebrates in aquaria with microscopic plastic <2 mm in diameter. The microscopic plastics were ingested by polychaete worms, barnacles, and amphipods during these laboratory trials. Documentation of transmission of these types of particles up the food pyramid has been provided by Eriksson (2003), who surveyed Southern Fur Seal Scat on Macquarie Island. She found that all scat contained plastic particles associated with the night-feeding myctophids (Lantern fish), active near the sea surface, and consumed by the seals.

When plastic debris hits the sea, the proportion that floats heads for surface accumulation zones. Modeling done by Ingraham using the Ocean Surface Current Simulator (OSCURS) seeded 113 drifters uniformly over the North Pacific from the U.S. Coast to China. After 12 years, winds and currents had gathered 75% of the drifters into an area of the Central Gyre equal to 28% of the total area seeded (Ingraham, 2000). The five enormous high-pressure gyres in the oceans comprise 40% of the sea surface, or 25% of the area of the entire earth. The mountains of air that create the highs force the sea level lower near their centers and create accumulation zones described as "gentle maelstroms" (Moore, 2003). These areas are in the deep ocean and are oligotrophic, oceanic deserts. Thus, the ratio of plastic particles to plankton is highest here on average, although after heavy rains cause runoff of plastic particles from urban areas, higher ratios are found near urban coastal zones (Moore, 2002, 2004). Detritus feeders, like the Laysan albatross, have been demonstrated to feed primarily in and around the gyres (Henry, 2004), and the stomach contents of their chicks, receiving nutriment only by regurgitation from adult birds, contain alarming quantities of plastic (Auman, 1997). Sileo documented eighty species of seabirds to ingest plastic in 1990. Carpenter found plastic pellets in eight of fourteen species of fish and one chaetognath in 1972 off Southern New England. Steimle found pellet ingestion more common in lobster than winter flounder in the New York Bight in 1991 (USEPA, 1992) (Figure 2).

Plastics as a means to transport pollutants to organisms in aquatic and marine ecosystems have become the focus of scientific research as levels of macro and micro plastics in these environments increase (Thompson, 2004). Mato and Takada (2001) at the Tokyo University of Agriculture and Technology have studied how polypropylene (PP) pellets in the marine environment adsorb, (with adsorption coefficients of 10^5-10^6 from ambient seawater), and transport PCBs, DDE and nonylphenols (NP). Field and laboratory studies of the physiological effects on seabirds that ingest contaminated plastic resin pellets were in progress at this

University when I visited there in March of 2006. We found polycyclic aromatic hydrocarbons and phthalates in all marine and river samples of pre-production plastic pellets, and post consumer fragments, of the same general size, < 5mm(Moore, 2005). In the ocean broken down bits of polymeric material are assuming the characteristics of a new class of sediments, floating on the surface, mixed into the water column, and embedded in bottom sediments and beach sand (Colton, 1974, Rios, in press). An invertebrate micro-plastic ingestion study is in the initial stages at the Southern California Coastal Water Research Project, and we are conducting feeding experiments on larval fish and moon jellies at our lab at the Cabrillo Marine Aquarium in San Pedro, CA with funding from the PADI Foundation. Studies by Gregory (1996), Moore (2005), and Zitko and Hanlon (Derraik, 2002) have drawn attention to small fragments of plastic derived from hand cleaners, cosmetic preparations, airblast cleaning media, and production waste from plastic processing plants. The quantities and effects of these contaminants on the marine environment have yet to be fully determined, but in a study conducted on the Los Angeles and San Gabriel Rivers in 2004-5, our sample analysis with extrapolation found 2 billion plastic particles of all types, <5 mm in size, flowing toward the ocean in three days of sampling (Moore, 2005). The extent to which compounds added to plastics at the time of manufacture or sorbed from the environment desorb when ingested by different organisms has not yet been studied. Whether or to what extent estrogenic compounds in plastics are implicated in findings such as a high percentage of intersex in Mediterranean swordfish (De Metrio, 2003), has not been investigated, but the presence of micro plastics in the sea surface microlayer where xenoestrogens are known to accumulate, has been documented by Ng (2005).

2.4 Collateral Concerns

Just as plastics are infinitely variable, so are the concerns raised by their ubiquitous presence as poorly controlled non-degradable waste. Foremost among these concerns is the recent exponential explosion in what may be termed "pelagic plastics." For most of their history, synthetic, petroleum-based polymers were used and discarded principally in Europe and the United States, and more recently, Japan. Levels of plastic pollution off these coasts paralleled the level of plastic production until recently (Thompson, 2004, Ogi, 1999, Moore, 2001). During the last decade of the 20^{th} Century, and continuing to the present, proliferation of plastic packaging and products accelerated worldwide. Sales of plastic water bottles alone rose from 3.3 billion in 1997, to 15 billion in 2002 (Container Recycling Institute). Many of these bottles are shipped around the world for disaster relief and other purposes, where no recycling infrastructure exists. Dr. Curtis Ebbesmeyer, of the Beachcombers and Oceanographers International Association, has estimated that a single, one liter plastic water bottle will photodegrade into enough pieces to put one on every mile of beach in the world (personal communication). Studies (Ogi, 1999, Moore, 2001, Barnes, 2002) show that the increase in micro-plastic marine debris is now exponential, going up by a factor of ten every two to three years in the most extreme case off Japan. There are now 25,000 plastic processors in India and China, consuming nearly as much plastic resin, 49.8 mt/yr, as the United States (Mehta, 2007). Exports of primary plastic resins from the Middle East are growing rapidly in every global market except North and South America (Al-Sheaibi, 2002) Consumer plastics are going global. Tracking their fate is difficult if not impossible. Based on statistics compiled in a 2003 California "Plastics White Paper," that included amounts of plastics made, disposed of, and recycled nationwide, approximately 25% of all disposable plastics remain unaccounted for (CIWMB, 2003). With total U.S. thermoplastic resin sales at $50x10^6$ tons, $25x10^6$ tons (50%) is disposed of as municipal waste, 5% is recycled and an estimated 20% is made into durable goods, leaving 12.5 million tons (25%) unaccounted for. Much of that 12.5 mt of unaccounted for plastic makes its way via rivers to the sea. In three days of sampling on the Los Angeles and San Gabriel Rivers, AMRF found 60 tons of plastic debris flowing towards the sea, representing 2.3 billion individual pieces of plastic trash of all size classes >1 mm (Moore, 2005).

Many islands, which act as sieves for ocean borne plastics, have already been heavily impacted by plastic debris originating far from their shores. On the surface of one square foot of beach sand on Kamilo Beach, Hawaii, 2,500 plastic particles >1 mm were found, and the fact that 500 of them were pre-production plastic pellets, with no processors located in Hawaii, lends credence to the concept that these particles are of foreign origin (Moore, unpublished data, 2003). McDermid (2004) collected 19,100 plastic particles from nine remote Hawaiian beaches separated by 1500 miles, and 11% were pre-production pellets by count. These pellets come in a variety of shapes, including rounded, flattened oval, and cylindrical, and are normally < 5mm in diameter. Plastic producers make these pellets, then ship them to plastic manufacturers or processors to be melted into consumer products. A 1998 study of Orange County Beaches in Southern California showed plastic pellets to be the most abundant items, with an estimated count of over 105 million, comprising 98% of the total debris (S. Moore, 2001). Southern California has the largest concentration of processors in the western United States. A 2005 study by AMRF of the two main rivers draining the Los Angeles, California basin found in one dry and two rainy days of sampling, over $2.3x10^9$ plastic objects and fragments being transported to the Pacific Ocean at San Pedro Bay. Macro debris >5 mm accounted for 10% of the total. Of the identifiable objects, the largest single component was pre-production plastic pellets at 2.3×10^8 (Moore, 2005). Ignoring these inputs results in underestimates of the total pieces of litter entering the ocean worldwide on a daily basis, like the widely quoted figure of 8 million pieces per day (UNEP). In reality, 8 million is only one per cent of the total number of plastic pieces flowing to the sea from the Los Angeles area in a single day, based on AMRF's three-day totals. AMRF's figures do not include anthropogenic debris other than plastic.

Plastics form a stable substrate for colonization by marine organisms, with larger floating items generally having one side exposed to the sun, and one side ballasted with fouling organisms. Less than 10% of the micro debris in a 1999 North Pacific Central Gyre study, however, appeared to have fouling organisms at all. I believe this may be due to their frequency of tumbling in wavelets and changing the side exposed to the sun. Barnes (2005) estimates "that rubbish of human origin in the sea has roughly doubled the propagation of fauna in the subtropics and more than tripled it at high (>50°) latitudes." Globally, the proportion of plastic among marine debris ranges from 60 to 80%, although it has reached over 90-95% in some areas (Derraik, 2002). Bartram (2000) points out certain exceptions to these generalizations found in United Kingdom beach surveys, and states that, "Litter sourcing seems to be highly site specific."

A report by the United Nations Environmental Programme titled, "Marine litter – trash that kills," states: "Marine litter is found resting or drifting on the seabed at all depths. In the North Sea, it has been estimated that some 70 per cent of the marine litter ends up on the seabed. Assessments made in the Dutch sector of the North Sea have indicated an average of over 110 pieces of litter per km^2 of seabed. If this is characteristic of the North Sea at large, a volume of at least 600,000 m^2 of marine litter could be found on the seabed. During a survey in the Mediterranean, 300 million pieces of garbage were found at a depth of 2,500 meters between France and Corsica. Consequently, large quantities of the entire input of marine litter around the world could be sinking to the bottom and be found on the seabed, both in shallow coastal areas and in much deeper parts of seas and oceans." Plastics made up 80-85% of the seabed debris in Tokyo Bay (Kanehiro, 1995). The consequences of partially covering the seabed with materials resistant to gas and water transport have not been fully investigated, although Katsanevakis et al, (2007) found a deviation in the community structure of the impacted benthic surface from their control and a clear successional pattern of change in benthic community composition. Goldberg has speculated that benthic debris may interfere with carbon cycling in the ocean.

In a 2003 article entitled: "Trashed," in Natural History Magazine, I speculated that the weight of plastic debris on the surface in an area of the North Pacific Central Gyre known as the "Eastern Garbage Patch," an area 1000 kilometers in diameter, was about three million tons, based on a published average of 5114g/km^2. (Moore 2001). Andrady (2000) found that plastic fishing gear "would initially increase in density because of copious fouling," and become negatively buoyant until it descended below the photic zone where the foulant colony would likely die due to lack of sunlight, allowing the plastic material to float again. I believe this implies that as buoyant plastic fragments become entangled in marine "snow" (the natural detritus of the marine environment), they may prevent it from reaching the sea floor where it is a major sequestration mechanism for atmospheric CO2.

3. SOLUTIONS

Because of the enormous diversity of plastic waste, which includes nearly every consumer and many industrial products, the solutions to the plastic debris problem are also diverse. Despite the recent upsurge in development of solutions for plastic pollution, the author is not aware of reports showing measurable overall reductions to this rapidly increasing despoiler of marine and aquatic environments.

3.1 Structural Controls

Devices to capture plastic debris before it reaches rivers and oceans are being installed at urban catch basins, storm drains and pumping stations, and debris booms are being placed across rivers draining urban areas. Containment structures cover only a small percentage of debris conduits, and during heavy storms, these devices break or overflow, and release debris. Nevertheless, these devices are being relied upon by municipalities required to reduce trash input to urban waterways by regulations called TMDLs (Total Maximum Daily Loads) used by Water Resource Control Boards to regulate pollutants entering urban waterways. Structural controls typically capture macro >5 mm debris only, as the legal definition of trash under the TMDL is anthropogenic debris that can be trapped by a 5 mm mesh screen. (California Regional Water Quality Control Board, Los Angeles Region). Based on our study of the Los Angeles watershed, 90% of plastic debris by count and 13% by weight are micro-debris < 5 mm (Moore, 2005).

3.2 Beach and Reef Cleanups

While beach cleanups by civic groups raise awareness among the general public of the plastic debris problem, they are infrequent and do not stem the tide of debris. In municipalities that regularly groom their beaches mechanically, the amount of debris removed depends on amount of rainfall, not on frequency of cleaning. In the Northwest Hawaiian Islands, the National Oceanic and Atmospheric Administration spends 2 million US dollars per year to remove 60 tons of derelict fishing nets and gear in an effort to save the critically endangered Hawaiian Monk Seal, over 200 of which have become entangled since records were kept (Foley, 2005). The amount retrieved does not diminish year to year, and efforts are currently being made to find accumulation zones where the nets can be retrieved at sea before they damage coral reef habitat. Recently, civic groups have begun to focus cleanup efforts on storm drains and catch basins upstream from outlets to the sea, which will prevent the debris removed from reaching the ocean.

3.3 Deposits, Fees

Ten of 52 U.S. states have implemented "bottle bills" which require a deposit on certain plastic bottles to aid in their recovery and recycling, and in 2005, only 17% of the over 50 billion polyethylene terephthalate (PET) plastic water bottles consumed in the U.S. were recycled. The number of plastic bottles as a percentage of total debris recovered in beach cleanups is rising (Container Recycling Institute). Thin high-density polyethylene (HDPE) and thicker LDPE shopping bags are recycled at a rate of around 1% in the U.S (USEPA, 2003), with trillions being produced worldwide. Many become airborne and soar to waterways and seas on the wind. An effort to put a deposit on the bags in San Francisco, California, was met with resistance by industry and failed, although eleven countries have such fees, and thirteen countries have enacted complete or partial bans (ERF). Recently, a BBC photographer, after documenting the effects of plastic waste on the Hawaiian Archipelago, returned to her hometown of Modbury, UK, and succeeded in getting the town's merchants to stop using plastic bags. This movement has spread to other towns, and the Mayor of London is now considering a 10 pence tax on the bags (Rebecca Hosking, personal communication)

3.4 Source Reduction, Take Back Schemes

Because plastic packaging extends the shelf life of products by providing an air and moisture barrier, it is increasingly used in global trade. In some applications, where space is at a premium, bulk, rather than individual containers are preferred, but the trend is for more individual packaging. Producers of consumer plastics in the United States have little incentive to minimize the use of their products, or to design them for ease of recycling. The prevailing attitude among U.S. manufacturers is that they are responding to the demands of the market, and that it is the responsibility of individuals and governments to create infrastructure for dealing with the resultant waste. Rarely are U.S. processors required to subsidize the cost of land filling or otherwise disposing of the plastic products they manufacture, which often become fast-track waste. A few U.S. companies have adopted a "zero waste" policy, which requires that their suppliers take back packaging, and they provide take-back programs for their customers, but these companies remain a small part of industry as a whole.

European countries, however, are responding to "green dot" initiatives with some packaging reductions. In December 1994, the European Union issued the "Directive on Packaging and Packaging Waste." This legislation places direct responsibility and specific packaging waste reduction targets on all manufacturers, importers and distributors of products on the EU market. To meet the requirements of this legislation, manufacturers, importers and distributors must either develop their own take-back scheme or join industry-driven non-profit organizations, such as the Green Dot Program, to collect, sort and recycle used packaging. Green Dot is currently the standard take-back program in 19 European countries and Canada. Such programs encourage product and packaging design that gives waste value when it is recycled as another product in a "cradle to cradle" system (McDonough, 2002). Such schemes may help to reduce plastic waste that ends up in the ocean, but they are far from universal.

3.5 Industry Housekeeping

Pre-production plastics (in the form of pellets or powders) are discharged to waterways during the transport, packaging, and processing of plastics when Best Management Practices (BMPs, i.e., proper housekeeping practices) are not adequately employed. For pellets transported by rail, cars are emptied via a valve that connects to a conveyance suction hose. The valve should be capped when not in use. Caps are often not replaced, causing pellet loss within the rail yard adjacent to a facility. A similar conveyance system exists for resins transported by hopper trucks. Pellets and powders escape when hoppers are emptied through pipes connected to valves at the bottom of the truck. When handled improperly, resin pellets and powders are also released from conveyance mechanisms on site. In addition to plastic resins, additives used for coloring or creating specific characteristics of processed plastics are also delivered in pellet and powder form. The discharges to local waterways include colorants and additives, not just plastic resins. Grindings, cuttings and fragments from the processing of plastics, known as production scrap, are often part of the mix of debris that is conveyed by wind, storm water, or runoff from plastics facilities to storm drains and nearby waterways.

Evidence suggests that pre-production plastic resin pellets accidentally released from plastic processors contribute approximately 10% by count to the plastic debris problem (Moore, 2005, McDermid, 2004). In response, the American Plastics Council (APC) and the Society of the Plastics Industry (SPI) in the United States have adopted a voluntary program of BMPs known as "Operation Clean Sweep." Operation Clean Sweep (OCS) was first developed in 1980 by SPI. It was recently revised and improved by a collaborative effort between AMRF, APC, and SPI. Measurements of industrial discharge before and after implementation of the program showed reductions of approximately 50% in pellet discharge (Moore, 2005), but because of the voluntary nature of the program, only a small percentage of the industry participates.

Monitoring done by AMRF indicates reductions of pellet loss of greater than 50% can result from getting processors to implement the voluntary program (Moore, 2005). Recruiting processors to the program has proved challenging, however, and I believe that less than one per cent of the plastic processing industry participates in OCS.

Pellets, powders, and fragments are widely dispersed from their places of origin. The impacts of powders and plastic debris smaller than pellets are not known but ingestion by plankton and other small marine organisms does occur (Moore, 2001, EPA, 1992). The impacts of pelletized and powdered plastic additives, including colorants and conditioning chemicals, in the marine environment are not well understood, as research is in the initial phases.

3.6 Recycling

Plastic is lipophilic and hard to clean. It is also difficult to separate composites and mixed plastic waste into the many different plastic types that require different reprocessing technologies. Furthermore, many thermoplastics melt at temperatures not far above the boiling point of water. Therefore, oily contaminants are not driven off during remanufacture. The price of recycled plastic materials often exceeds the current price of virgin plastic resin. Because of contamination, recycled plastics can rarely be used in true "closed loop" recycling; for example, a layer of virgin plastic must be added onto the recycled material for food contact applications. Plastic bags are often used to make plastic wood, rather than more bags. Plastic wood is not widely recycled and most will end up land filled or otherwise discarded. In spite of separation schemes for households, only about 5% of plastics in the U.S. are recycled in any way (CIWMB, 2003).

3.7 Bans, Legislation

Bans typically focus on high profile waste, such as thin plastic shopping bags and expanded polystyrene cups and clamshell food service containers (commonly but incorrectly called Styrofoam, which is a patented insulation made by Dow Chemical Co.). Bans on some bags and foamed plastics have been adopted by several municipalities in the United States and by some other countries, but most types of plastic packaging and consumer products are unregulated and continue to litter the landscape, and make their way to the ocean.

3.8 Biodegradables

Many polymers originate from non-petroleum sources. In general, these plastics biodegrade more rapidly than their petroleum-based counterparts. However, typical tests for biodegradability rely on hot, aerated composting media, rich with bacteria and fungi. The marine environment is cold and devoid of fungi by comparison, and many compostable "bioplastics" degrade very slowly, or hardly at all in the deep ocean (Wirsen, 1971). Currently, substitution for conventional plastics is limited by the cost of bioplastics, which are five to ten times greater than petroleum-based resins. A 1999 projection of the world biodegrables market was that it would grow from 30 to $250x10^6$ pounds per year, while petroleum plastics sell at one thousand times that rate, or $250x10^9$ pounds annually (New York Times, 1999).

4.0 Recommendations

In 2002, the State of California Water Resources Control Board awarded a half-million dollar grant to AMRF and the California Coastal Commission (CCC) to assess the amount of plastic debris entering the ocean from the Los Angeles Basin's two largest watersheds. The grant provided for a process to develop recommendations to reduce these inputs. During the first international conference on plastic debris, called "Plastic Debris, Rivers to Sea," the participants were encouraged to participate in writing these recommendations. The result was a comprehensive booklet, published in 2006 and available online at: http://plasticdebris.org/CA_Action_Plan_2006.pdf. It included 63 recommendations for action which were grouped into the following categories:

1. The Need for Improved Coordination
2. Research Needs
3. Specific Sources of Land-based Discharges
4. Product Wastes

In part as a result of these recommendations, the California Ocean Protection Council adopted a resolution on marine debris, available in its entirety at http://resources.ca.gov/copc/02-08-

07_meeting/Adopted_Marine_Debris_Res_0207.pdf, which listed many of the recommendations found in AMRF and the CCC's Action Plan.

Certain California legislators then proposed, under the mantle of "The Pacific Protection Initiative," two Assembly bills and two Senate bills to address marine debris issues. Their content and current status can be viewed at: http://www.healthebay.org/currentissues/ppi/ . Details of international legal and other actions to deal with marine debris are beyond the scope of this review, and the author is not aware of any clearinghouse for this type of international data, but such a clearinghouse would be of benefit to those seeking solutions to the problems caused by persistent plastic debris.

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FIGURE LEGENDS

Figure.1 Trawl Sample, Aug., 2005, AMRF survey: 400 No.L., 1400 W.Lo. Photo: Capt. Charles Moore.

Figure 2. Laysan albatross chick, Kure Atoll, 2002, photo: Cynthia Vanderlip, www.algalita.org

FIGURE 1

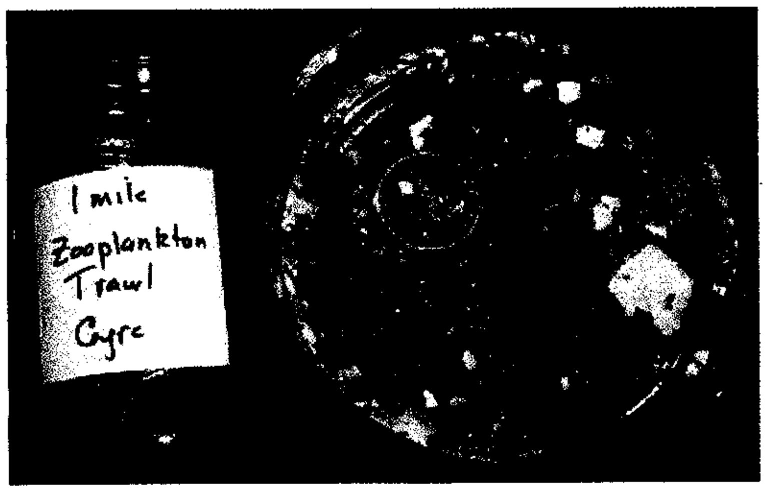

Fig. 1 Trawl Sample, Aug. 2005, AMRF survey; 40° N.L., 140°W.Lo. Photo: Capt. Charles Moore

FIGURE 2

Fig.2 Laysan albatross chick, Kure Atoll, 2002, photo: Cynthia Vanderlip, www.algalita.org

Table 1. Effects of Two Additives on the Densities of Selected Commodity Resins with types of plastic found in Gyre Sample 11.

Average surface seawater density 1.027

Polymer	Density Without Additive	Density With Additive
ABS	1.01 to 1.08	1.18-1.61[a]
Polyamide (nylon)	1.07-1.08	1.13-1.62[a]
Polyethylene (75% of Gyre Sample #11)[*]	0.92-0.075	1.18-1.28[a]
Polypropylene (18% of Gyre Sample #11)[*]	0.89-0.91	1.04-1.23[a] 1.22-1.17[b]
Polystyrene (1.8% of Gyre Sample #11)[*]	1.04-1.08	1.20-1.50[a]
PVC (0.4% of Gyre Sample #11)[*]	1.30-1.58	1.42-1.50[a] 1.30-1.70[b]
Polycarbonate	1.2	

[a] Additive: Fiber/flake reinforcer.

[b] Additive: Particulate filler

[*] Eriksson. 2002 (Report on plastic types found in Station 11,

Moore (2001) – See Note

Adapted from USEPA (1992) p 17:

Note: Gyre Sample 11 contained the most dense accumulation of plastic particles in our 1999 study published in 2001 (Moore), polymer analysis by Eriksson, (2002).

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A comparison of neustonic plastic and zooplankton at different depths near the southern California shore

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Abstract

Previous studies of neustonic debris have been limited to surface sampling. Here we conducted two trawl surveys, one before and one shortly after a rain event, in which debris and zooplankton density were measured at three depths in Santa Monica Bay, California. Surface samples were collected with a manta trawl, mid-depth samples with a bongo net and bottom samples with an epibenthic sled, all having 333 micron nets. Density of debris was greatest near the bottom, least in midwater. Debris density increased after the storm, particularly at the sampling site closest to shore, reflecting inputs from land-based runoff and resuspended matter. The mass of plastic collected exceeded that of zooplankton, though when the comparison was limited to plastic debris similar to the size of most zooplankton, zooplankton mass was three times that of debris.

Keywords: Southern California; Neuston; Plastics; Zooplankton; Debris; Pollution monitoring

1. Introduction

Most studies of marine debris have focused on large, visible material found on beaches, with only a few studies describing abundance of small material in the water column (Derraik, 2002). The earliest of these in the Pacific was Shaw and Mapes (1979) who found a high density of plastics near the surface. More recent studies have shown that the mass of neustonic plastic can be comparable to that of zooplankton in both the mid-Pacific gyre (Moore et al., 2001) and along the California coast (Moore et al., 2002).

Studies of neustonic debris have been limited so far to sampling of surface waters. While some birds feed on plankton near the surface and could potentially consume surface debris, most filter feeding occurs below the surface. Plastics make up a high percentage of neustonic debris and many plastics are positively buoyant. Therefore, studies limited to collection in surface waters have the potential to overestimate prevalence of debris in the water column.

Our study extends previous work by comparing the density of neustonic debris and zooplankton at several depths along the California coast. The study also addresses how distribution in the water column changes following a storm event, when higher wind conditions and urban runoff have the potential to enhance vertical mixing.

2. Materials and methods

Sampling was conducted at two Santa Monica Bay sites offshore from Ballona Creek, which drains downtown Los Angeles. The first site was located approximately 0.8 km offshore and the second about 4.5 km offshore. Sampling took place on March 21, 2001 following six weeks without rain, and on March 25, 2001, following a 20 mm rain event.

The sampling site closest to shore was 15 m deep and was sampled near the surface and at 5 m depth. The second site was 30 m deep and samples were collected at three depths: surface, 5 m and near the bottom. Surface samples were collected using a 0.9×0.15 m^2 rectangular opening manta trawl with a 3.5 m long, 333 micron net and a 30×10 cm^2 collecting bag. Mid-depth samples were collected using paired 61 cm diameter bongo nets

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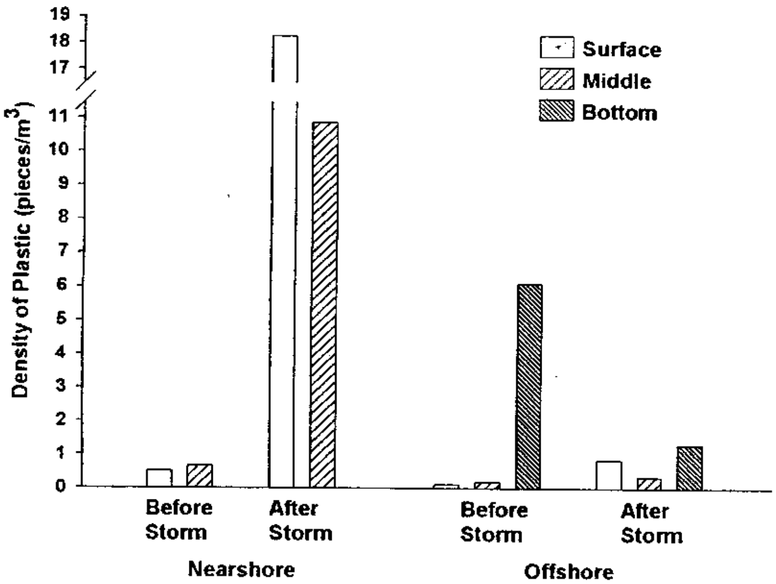

Fig. 1. Amount of plastic (pieces/m^3) before and after a storm at different depths and proximities to shore.

with 3 m long, 333 micron nets and 30×10 cm^2 collecting bags. Bottom samples were collected using a 31 cm^2 rectangular opening epibenthic sled with a 1 m long, 333 micron net and a 30×10 cm^2 collecting bag. The net on the epibenthic sample was located 20 cm from the bottom. Visual inspection by scuba divers showed sediment stirred from the bottom and did not enter the net. All samples were fixed in 5% formalin in the field, and later soaked in fresh water and transferred to 70% isopropyl alcohol.

Trawls were done parallel to shore for 10 min. Trawl speed varied between 1.0 to 2.3 m/s as measured with a B&G paddlewheel sensor, resulting in a trawl distance of between 0.5 and 1.0 km. A General Oceanics flowmeter was mounted across the net mouth during all deployments to measure the volume filtered.

In the laboratory, samples were placed in fresh water and floating plastic removed. A dissecting microscope was then used to remove remaining debris and plankton. Debris was sorted by category (plastics, tar, rust, paint chips, carbon fragments, and feathers) and plastics were further categorized (fragments, styrofoam, pellets, polypropylene/monofilament line, thin plastic films, and resin). Each category was sorted through Tyler sieves of 4.75, 2.80, 1.00, 0.71, 0.50 and 0.35 mm and counted. Plastics were oven dried at 65 °C for 1 h and plankton and plant material oven dried at 65 °C for 24 h, then weighed.

3. Results

Plastics were present throughout the water column on both sampling dates, but relative concentrations within the water column varied between dates and sites. The site closest to shore had nearly equal density at the two sampling depths before the storm (Fig. 1), but density on the surface was considerably higher after the storm.

Debris densities at surface and midwater depths of the offshore station were similar to that at the nearshore station; the increase in density after the storm was not nearly as large as at the inshore site. Debris density near bottom at the offshore station was considerably greater than at both the surface and midwater depths. Unlike surface samples, there was reduced debris density at bottom following the storm.

The spatial patterns for mass were similar to that of density, though the differences between dates were exaggerated (Fig. 2). For example, the weight of plastic increased by more than two hundred times on the surface after the storm. Much of this increase was attributable to the presence of larger items at surface after the storm (Table 1).

The average mass of plastic was 1.4 times that of plankton in this study, but much of the plastic mass was large material that is unlikely to be confused for planktonic prey (Table 2). When the comparison was limited to smaller particles (less than 4.75 mm), the mass of plankton was approximately three times that of plastics. This ratio was consistently higher near the surface and on the bottom than it was at mid-depth (Fig. 3).

4. Discussion

The plastic to plankton ratio that we observed near surface was similar to that found in previous studies (Table 2); ours was the first study, however, to measure it at other depths. While we found that there was more

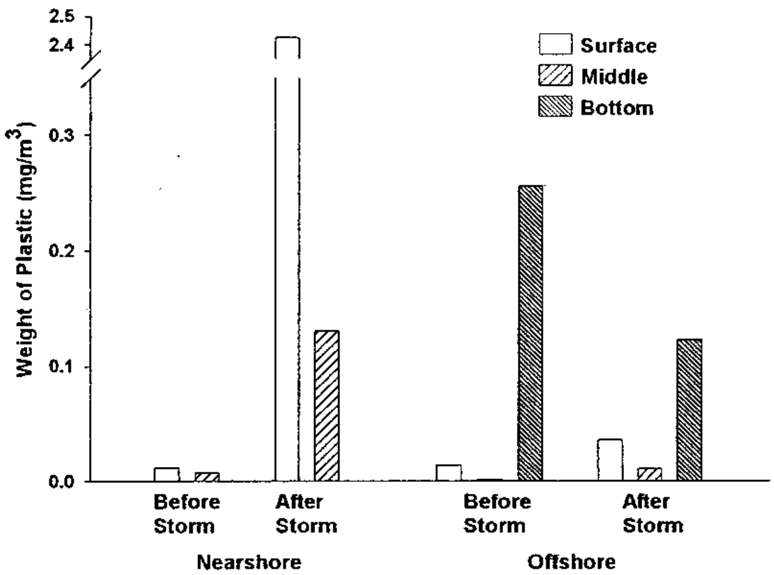

Fig. 2. Mass of plastic (mg/m^3) before and after a storm at different depths and proximities to shore.

Table 1
Percent weight and density of plastic by size and depth category

Size class	Category	Depth		
		Surface	Middle	Bottom
0.355–0.499	Weight	0.5	10.6	6.1
	Density	3.2	5.7	0.3
0.500–0.709	Weight	0.8	19.7	36.5
	Density	2.9	2.3	9.1
0.710–0.999	Weight	1.9	12.5	23.0
	Density	33.4	10.6	22.7
1.000–2.799	Weight	7.0	27.6	17.9
	Density	24.4	21.2	17.8
2.800–4.749	Weight	2.5	4.6	12.6
	Density	23.5	31.8	36.1
>4.750	Weight	87.2	25.0	3.9
	Density	12.6	28.4	14.0

Table 2
Comparison between this study, San Gabriel River study (Moore et al., 2002), and North Pacific Gyre study (Moore et al., 2001)

	Average debris		Ratio of plastic to plankton for mass	
	(g/m^3)	(pieces/m^3)	All debris	Debris <4.75 mm
This study	0.003	3.92	1.4:1	0.3:1
San Gabriel River study	0.002	7.25	2.5:1	0.6:1
Gyre study	0.034	2.23	6.1:1	0.3:1

debris near the surface than in midwater, we also found that there was more on the bottom than on the surface. When only small size classes were considered, there was little difference between surface and midwater densities.

It is commonly perceived that plastics are positively buoyant, but only 46% of manufactured plastics actually are (USEPA, 1992). Many buoyant items are products such as Styrofoam, in which air is injected. Even those plastics that are lighter than water at the time of manufacture can become negatively buoyant as they are fouled by biota or accumulate debris. We observed sand embedded in many items, such as plastic bags, that might otherwise float.

Few plastics are neutrally buoyant, which in the absence of turbulence would lead to a natural separation of debris top to bottom in the water column. The amount of turbulence necessary for resuspension of debris into midwater appears to be small. We observed that density near the bottom declined and midwater density was elevated after a storm, suggesting that storm or wind-related turbulence may be adequate for resuspension. This is consistent with the density of most plastics differing from that of seawater by a small amount (USEPA, 1992).

While mixing occurred in the shelf waters we sampled, the influence of resuspension in deeper waters is less clear. The distance from bottom to the middle of the water column is greater in deeper waters, meaning that more turbulent energy is required to resuspend bottom material to the middle of the water column and the influence of wind on mixing decreases with depth. Still, our study suggests that there is sufficient routine turbulence that potential biological effects of plastics in the water column are not limited to surface waters.

Many marine fauna are known to ingest debris (Fowler, 1987; Bjorndal et al., 1994; Robards et al., 1995; Blight and Burger, 1997), but few studies have

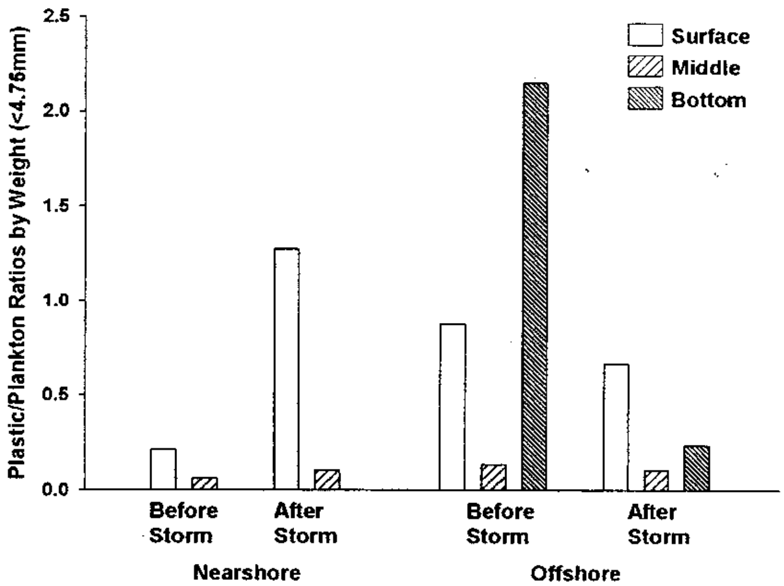

Fig. 3. Plastic/plankton ratios (pieces less than 4.75 mm) before and after a storm at different depths and proximities to shore.

examined whether they become artificially sated on this non-nutritive material (Ryan, 1987). Mato et al. (2001) found that contaminants adsorb to plastics, creating a potential for indirect effects of debris consumption; however, no study has considered whether this is a viable pathway for contaminant uptake by biota. These kinds of studies need to be conducted before we can fully assess the importance of debris in the water column.

Acknowledgements

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4. Discussion

The density of neustonic plastic along the southern California coast was about three times higher than C.J. Moore et al. (2001) found in the mid-Pacific gyre, though the mass was 17 times lower (Table 3). This disparity between density and mass reflects the dramatic difference in size of neustonic debris between the gyre and the coast. Most of the neustonic plastic mass observed in the North Pacific central gyre was large material associated with the fishing and shipping industry. Most of the plastic we observed near the coast were small fragments attributable to land-based runoff.

The average plastic:plankton mass ratio was less in southern California, reflecting its higher plankton density. However, the plastic to plankton ratio on the day after the storm was higher in southern California than in the North Pacific central gyre. This change resulted from an increase in debris following the storm, rather than from a reduction in plankton. Moreover, the ratio in the North Pacific central gyre was driven by large debris. When the comparison of ratios between these two areas is limited to debris smaller than 4.75 mm, which is the fraction that filter feeders are most likely to confuse with plankton, the southern California ratio becomes twice that of the North Pacific central gyre.

The differences between our findings and those in the North Pacific central gyre largely reflect differences in proximity to land-based sources, but the effects of land-based runoff are probably exaggerated in southern California compared to the rest of the country. Southern California rivers are highly modified stormwater conveyance systems that are independent of the sewage treatment system, so urban debris flows unimpeded to the ocean. Moreover, southern California has an arid environment with a short rainy season and long dry periods when the rivers provide minimal runoff. Thus, land-based debris will accumulate between storms and enhance the amount of runoff following a storm compared to more temperate areas.

Reducing marine debris is a worldwide concern; however, in southern California it presents a different challenge than in the North Pacific central gyre or other open water areas. In the open ocean, the input materials are larger and the sources far more diffuse. Here, the land-based sources are more definable, but the material is smaller and therefore harder to capture. Several steps are being taken to reduce land-based contributions to the coastal ocean. Barrier nets to capture larger debris have recently been constructed on several of the largest river systems in southern California. The Los Angeles Regional Water Quality Control Board has set a total maximum daily load of zero trash for several area watersheds. However, these orders focus on the large debris (>5 mm) and the aesthetic effects they have on beaches and harbors. Presumably some of the same management steps will serve to reduce the smaller fragments, but it is unclear to what extent.

It is also unclear what effects that the plastic debris we observed in coastal waters have on planktonic filter feeders. Little is known about how ingestion of plastics affects filter feeders, though plastics have been shown to adsorb contaminants (Mato et al., 2001). Moreover, our study, as well as that of C.J. Moore et al. (2001), was limited to the upper water column. While some filter feeders focus their consumption on the upper water column, most pelagic feeders use a much larger portion of the water column than we sampled and density of debris compared to that of plankton has not been investigated deeper in the water column.

Table 3
Comparison between this study and the North Pacific central gyre study (Moore et al., 2001)

	Average debris		Ratio of plastic to plankton for mass	
	(g/m^3)	($pieces/m^3$)	All Debris	Debris <4.75 mm
This study	0.002	7.25	2.5:1	0.6:1
Gyre study	0.034	2.23	6.1:1	0.3:1

Acknowledgements

The authors wish to thank Kevin Herbinson of Southern California Edison and Giancarlo Cetrulo of the Los Angeles Conservation Corps for the use of the S.E.A. Lab in Redondo Beach, California.

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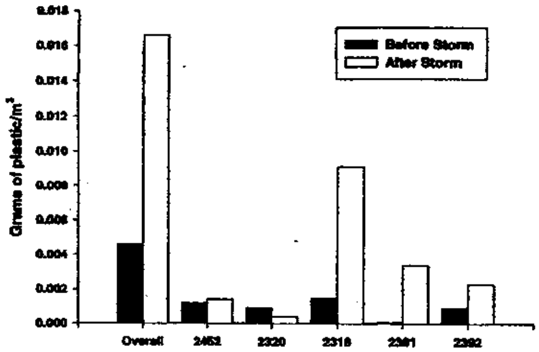

Fig. 3. Debris ratios for mass (g/m^3) of debris before and after a storm for the San Gabriel River debris study, October, 2000 and January, 2001.

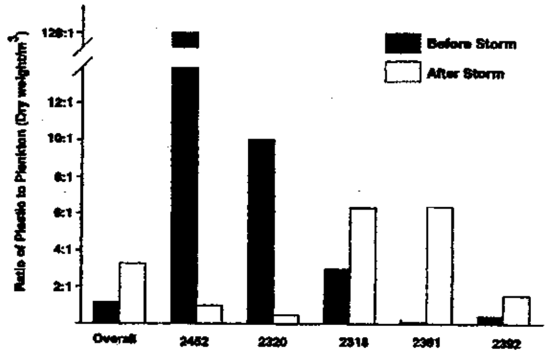

Fig. 4. Plastic and plankton ratios before and after a storm for the San Gabriel River debris study, October, 2000 and January, 2001.

storm, though the storm effect on mass was less than it was for abundance (Fig. 3). This reflects the smaller average size of plastic particles that we observed after the storm (Table 1).

The spatial distribution of debris also differed before and after the storm. Prior to the storm, the mass of plastic debris was greatest at the three stations closest to land (Fig. 3). After the storm, mass of debris was greatest at the three stations farthest from land.

The mass of plastic was about two and a half times higher than that of plankton across the entire study. Following the storm, this ratio exceeded 3:1 (Fig. 4). The spatial pattern of the ratio also differed before and after the storm. Before the storm, the highest plastic to plankton ratios were observed at the two stations closest to shore, whereas after the storm these stations had the lowest ratios.

Most of the debris was in the form of plastic fragments regardless of sampling date and sampling location (Table 2). Thin plastic films, such as those used in garbage and sandwich bags, was the second most common type of debris, but it exceeded 5% of the mass only at the station closest to land after the storm. Styrofoam, fishing line and plastic pellets never exceeded 2% of the mass at any station.

Table 1
Percent of each debris size class before and after a storm for the San Gabriel River debris study, October, 2000 and January, 2001

Small plastics	Percent of each debris size class by station									
Size class (mm)	2452		2320		2318		2391		2392	
	BS	AS	BS	AS	BS	AS	BS	AS	BS	AS
0.355–0.499	0.1	8.9	3.1	21.2	2.4	0.1	4.2	7.0	1.9	2.4
0.500–0.709	0.1	8.4	2.3	20.6	9.6	2.9	12.3	13.8	3.7	9.3
0.710–0.999	0.1	3.1	2.0	13.9	1.7	12.7	9.2	11.0	10.7	21.0
1.000–2.799	1.9	14.1	10.2	35.1	13.3	24.8	0.8	22.1	34.0	13.1
2.800–4.749	1.5	56.1	0.0	4.1	2.2	39.2	0.0	9.6	49.7	1.5
>4.750	96.2	9.5	82.3	5.1	70.9	20.3	73.5	36.5	0.0	52.7

BS: Before storm; AS: After storm.

Table 2
Percent of each debris type before and after a storm for the San Gabriel River debris study, October, 2000 and January, 2001

Debris type	Percent of each debris type by station									
	2452		2320		2318		2391		2392	
	BS	AS	BS	AS	BS	AS	BS	AS	BS	AS
Fragments	100.0	93.7	95.9	96.5	94.8	94.0	100.0	98.8	100.0	92.7
Styrofoam	0.0	0.6	2.1	0.9	0.0	0.0	0.0	0.3	0.0	1.8
Pellets	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.3	0.0	1.8
Line	0.0	0.6	2.1	0.9	2.6	6.0	0.0	0.3	0.0	1.8
Thin films	0.0	5.1	0.0	0.9	2.6	6.0	0.0	0.3	0.0	1.8

BS: Before storm; AS: After storm.

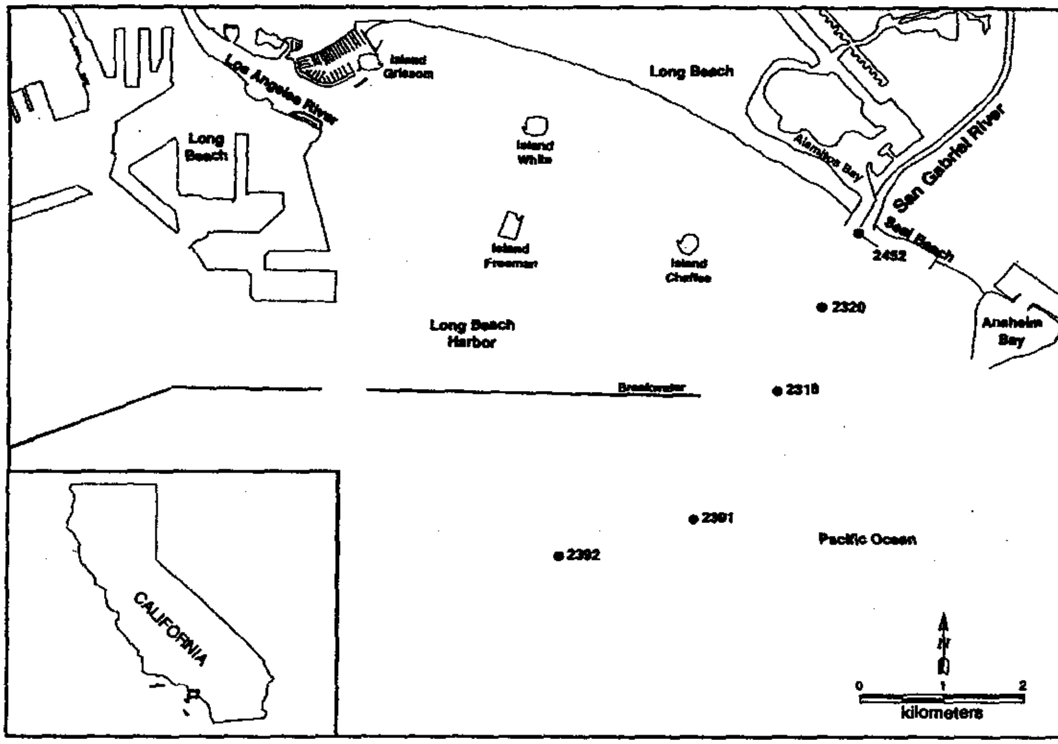

Fig. 1. Map of station locations and area of the San Gabriel River debris study, October, 2000 and January, 2001.

on each survey (Fig. 1). The first station was located approximately 200 m offshore in front of the San Gabriel River mouth and the farthest station was about 5 km from shore.

Samples were collected using a manta trawl with a 0.9×0.15 m^2 rectangular opening (behind a G.O. flowmeter) and a 3.5 m long, 333 u net with a 30×10 cm^2 collecting bag. The net was towed at the surface at a nominal speed of 1.5 m/s. Actual speed varied from 1.25 to 2.5 m/s as measured with a B&G paddlewheel sensor. Trawl transects were between 0.5 and 1.0 km long and were laid out in an east/west orientation. Samples were fixed in 5% formalin, soaked in fresh water, and transferred to 70% isopropyl alcohol.

Samples were split using a Folsom plankton splitter after large pieces of debris and plant material were removed. Samples were sorted through Tyler sieves of 4.75, 2.80, 1.00, 0.70, 0.50, and 0.35 mm. Debris, zooplankton and plant material were separated from the sorted fractions using a dissecting microscope; debris were categorized into fragments, Styrofoam, pellets, polypropylene/monofilament line, thin plastic films, resin and nonplastics (including tar, rust, paint chips, carbon fragments) and counted. Plankton and plant material were wet weighed and plastic, plankton and plant material then oven dried at 65 °C for 24 h and weighed.

3. Results

Abundance of neustonic debris was several fold higher on the sampling date following the storm (Fig. 2). Prior to the storm, density was around three pieces per cubic meter at the highest density station. After the storm, density was more than twice that at all stations. The mass of plastics was also generally higher after the

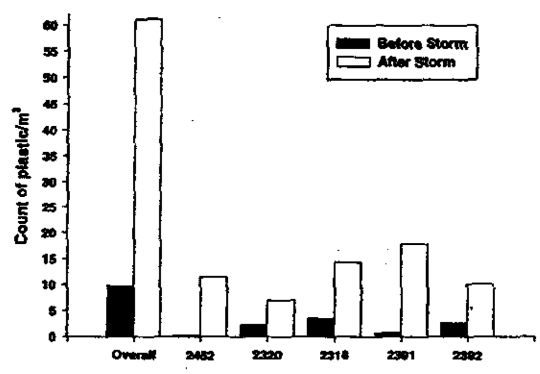

Fig. 2. Debris ratios for number of pieces (pieces/m^3) of debris before and after a storm for the San Gabriel River debris study, October, 2000 and January, 2001.

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A comparison of neustonic plastic and zooplankton abundance in southern California's coastal waters

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Abstract

The density of neustonic plastic particles was compared to that of zooplankton in the coastal ocean near Long Beach, California. Two trawl surveys were conducted, one after an extended dry period when there was little land-based runoff, the second shortly after a storm when runoff was extensive. On each survey, neuston samples were collected at five sites along a transect parallel to shore using a manta trawl lined with 333 μ mesh. Average plastic density during the study was 8 pieces per cubic meter, though density after the storm was seven times that prior to the storm. The mass of plastics was also higher after the storm, though the storm effect on mass was less than it was for density, reflecting a smaller average size of plastic particles after the storm. The average mass of plastic was two and a half times greater than that of plankton, and even greater after the storm. The spatial pattern of the ratio also differed before and after a storm. Before the storm, greatest plastic to plankton ratios were observed at two stations closest to shore, whereas after the storm these had the lowest ratios.

Keywords: Southern California; Neuston; Plastics; Zooplankton; Debris; Pollution monitoring

1. Introduction

Numerous researchers have documented the magnitude of marine debris and the threat that its ingestion poses to marine biota (Fowler, 1987; Ryan, 1987; Bjorndal et al., 1994; S.L. Moore et al., 2001). Most of these studies, however, have focused on large debris or debris that accumulates on the shoreline. Few studies (Shaw and Mapes, 1979; Day and Shaw, 1987) have examined the small floating debris that presents a potential risk to filter feeders, which have limited capacity for distinguishing small debris from planktonic food.

C.J. Moore et al. (2001) recently compared the density of neustonic plastic with that of potential zooplankton prey and found that mass of debris can rival zooplankton biomass in the upper water column. However, their study was conducted in the North Pacific central gyre, which is a large eddy system that can concentrate debris. Moreover, the gyre is a nutrient poor environment with low biological productivity, which would serve to exaggerate comparisons between debris and zooplankton. It is unclear whether a similar pattern occurs in other marine environments.

This study compares the density of neustonic debris and zooplankton along the southern California coast, an area that is subject to nutrient upwelling and has a higher biological productivity than the North Pacific central gyre. The study area is located adjacent to a major population center, providing additional geographic contrast because of the proximity to land-based sources of debris. To assess the importance of land-based sources, identical surveys were conducted after an extended dry period, when there was little land-based runoff and, shortly after a storm, when runoff was extensive.

2. Materials and methods

The first neustonic trawl survey was conducted on October 30, 2000, following 63 days without rain. The second was conducted on January 12, 2001, immediately following a 9 cm rainstorm. Five sites located sequentially offshore from the San Gabriel River were sampled

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WORKING OUR WAY UPSTREAM: A SNAPSHOT OF LAND-BASED CONTRIBUTIONS OF PLASTIC AND OTHER TRASH TO COASTAL WATERS AND BEACHES OF SOUTHERN CALIFORNIA

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Introduction

The most abundant type of debris impacting coastal beaches in Southern California's Orange County is pre-production plastic pellets, the plastic industry's principal feedstock. Hard plastic objects and pieces are over a hundred times less common but weigh one and a half times as much as the pellets[1]. The presence of pre and post consumer plastics in the marine environment and on beaches is not only a Southern California phenomenon. "The literature on marine debris leaves no doubt that plastics make-up most of the marine litter worldwide."[2] Murray Gregory showed in 1989 that plastic debris can be found throughout the southwest Pacific, with high densities of plastic in surface waters north of New Zealand, and abundant plastic pellets on New Zealand beaches adjacent to manufacturing centers.[3] Algalita Marine Research Foundation (AMRF) has documented land based sources of plastic and debris in neuston samples from the North Pacific Central Gyre[4] (NPCG) as well as along the Southern California Coast.[5] Plastic debris has also been shown to occur at subsurface depths of 10m and 30m in the NPCG,[6] Southern California coastal waters, and near the bottom of the sea floor off Ballona Creek.[7]

Most studies of marine debris have focused on easily visible and identifiable plastic objects. The studies by AMRF and Southern California Coastal Water Research Project (SCCWRP), however, have shown that plastic fragments less than 5mm have a mass that is 30% of the mass of the associated zooplankton in the NPCG. In near coastal waters off the San Gabriel River, the mass of plastic less than 5 mm was found to be 60% of the mass of the associated zooplankton.[7]

Policies in California have been established to restrict trash and plastic greater than 5 mm in size through the process of regulating Total Maximum Daily Loads (TMDLs). In order to quantify debris not subject to regulation by TMDLS, this study analyzed plastic trash between 1 and 5mm in size as well as that >5mm from two Southern California Rivers; the Los Angeles River and the San Gabriel River. The goal of this study was to answer the following questions:

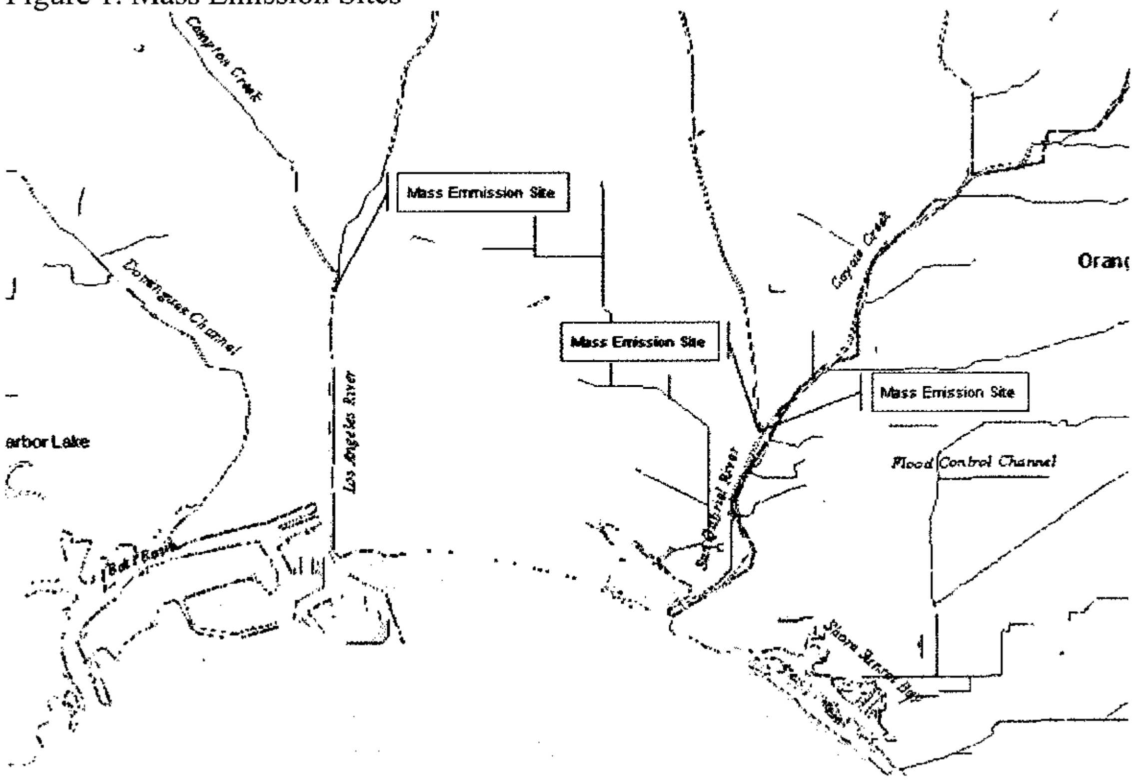
1) What are the amounts of different types of debris flowing down the rivers to the sea?
2) What are the quantities of debris in two size classes (1-4.75mm and >4.75mm) flowing down the rivers to the sea?
3) What is the weight of the debris flowing down the rivers to the sea?
4) What differences in the above quantities are observed in dry vs wet conditions?

Methods

Monitoring sites were selected in each watershed that represent a point at which all materials coming down the river from the watershed have to pass before reaching the ocean. Such sites are known as "mass emission" sites. Each was also chosen because it had access for sampling, and was above the area of tidal influence.

In the Los Angeles River one mass emission site was adequate, however, in the San Gabriel River two mass emission sites were necessary. One was located on the San Gabriel River and the other on Coyote Creek (see Fig. 1). These two sites are slightly upstream from where the Creek and the River merge. The reason for having two sites is that after they merge, they are subject to tidal influence.

Figure 1. Mass Emission Sites



The mass emission sites were sampled during both a dry and a wet period. The dry period was considered to be at least two weeks without 0.25" of rain, after which the dry period sample could be taken. The wet period samples were taken within 24 hours of a 0.25" rainfall. At each site grab samples were collected at the middle and edge of the channel, and at the surface and depth. For both wet and dry weather sampling, surface samples were collected at the center of the river using a manta trawl (see Table 1). Surface samples were also collected at the river/bank interface, and in laminar flow near the mid channel (Nov. 22 only) using two different sized hand nets. All nets used had less than a 1mm mesh. Mid-depth to bottom samples were collected using a heavy streambed sampler. A large crane was used to lower the manta net and the streambed sampler for sampling. During the high flow of the wet period, the use of a crane was not possible, instead, a heavily weighted rectangular net was dropped from an upstream bridge nearby, allowed to extend to the length of the rope, then pulled to the side of the river for the collection of the sample. The hand nets were again used along the side of the river/bank interface. Table 1 summarizes the characteristics of our collection devices.

Table 1. Collection Device Characteristics

Collection Device	Handnets	Manta Trawl	Streambed	Rectangular net
Net Aperture Dimensions (m)	.46 x .25 .43 x .22	.9 x .15	.15 x .15	.46 x .25
Mesh Size (mm)	.800 .500	.333	.333	.333
Usage	Surface Edge	Surface Middle	Bottom Middle	Surface Middle Subsurface Bottom(mostly)

Flow rate was determined by using a General Oceanics flowmeter, or the time and distance method of a floating object. The original sampling time was 15 minutes; however, due to fouling of the net and flowmeter by algae and debris in the Spring samples, some deployment times were as short as 30 seconds. Three sample replicates were collected with each device. All sampling times and devices were normalized to obtain count or weight per cubic meter of river water.

All samples were taken to the AMRF Lab and analyzed. The samples were sorted wet. The large debris was sorted out first and placed in the appropriate category, either natural, plastic, or manmade items. A dissecting scope was used to sort out the rest of the smaller plastic and manmade items from the natural debris. Tyler sieves were then used to size class the small plastic items (4.75mm, 2.8mm, 1.0mm). The sieved items were oven dried at 65° C. Further sorting separated the plastic into types (fragments, foams, pellets, line, and films). Each type was counted, weighed, and recorded.

After each sample was sorted, the density or load of plastic per cubic meter of river water was determined by dividing the quantity of plastic (count or mass) collected by the product of the flow rate of the river, the area of the opening of the sampling device and the length of time the device was deployed. The three replicate samples were then averaged for that sampling device.

Wet period samples were collected first (November 22 and December 28, 2004) at all three sites. Dry period samples were collected on April 11, 2005.

Results

Results are shown in the following tables for the counts and weights of debris by their size class and type on each of the three sample dates.

Tables 2 and 3 present our mass emission density findings by size class for the three sampling sites. Data is presented for count density (pieces/m^3), and weight density (g/m^3), with the indicated collection method.

Tables 4 and 5 present our mass emission density findings by type of plastic debris.

Tables 6-9 show estimates for a one-day (24 hr) total of each debris category using flow data taken from available Flood Control Agency river-flow totals for that date.

The total count density of particles in the Los Angeles River between 1 and 4.75mm in size, collected on 11-22-04 from all sampling devices was 12,933 pieces/m^3, while particles and whole objects greater than 4.75 mm from all sampling devices was 820/m^3. The highest count density from any sampling device used in the Los Angeles River was on 11-22-04 with the hand net in laminar flow near mid-channel at 12,652 pieces/m^3.

The total count density of particles in the San Gabriel River, including the Coyote Creek tributary, between 1 and 4.75mm in size, collected on 11-22-04 from all sampling devices was 411 pieces/m^3, while particles and whole objects greater than 4.75 mm from all sampling devices was 125/m^3. The highest count density from any sampling device used in the San Gabriel River or its Coyote Creek tributary was on 11-22-04 with the manta net; 171 pieces/m^3.

Table 2. Total Count Density (number/m^3)

	Coyote Creek		San Gabriel River		Los Angeles River	
	1 - 4.75 mm	>4.75 mm	1 - 4.75 mm	>4.75 mm	1 - 4.75 mm	>4.75 mm
November 22, 2004 (wet)						
Handnet	74	10	61	76	271	42
Manta	< 1	< 1	153	18	9	< 1
Streambed	< 1	< 1	123	21	< 1	< 1
Handnet Laminar	--	--	--	--	12652	777
December 28, 2004 (wet)						
Handnet	14	2	29	4	35	4
Thrownet	4	< 1	4	< 1	1	< 1
April 11, 2005 (dry)						
Handnet	2	< 1	< 1	0	22	22
Manta	5	< 1	<1	0	0	< 1
Streambed	< 1	0	0	0	<1	< 1

The highest weight density for any river sampled was in the San Gabriel River on 11-22-04, with the manta net at 81 g/m^3. The handnet data for the same date and location was half as much, and the laminar net on the LA River was 56 g/m^3.

Table 3. Total Weight Density (g/m^3)

	Coyote Creek		San Gabriel River		Los Angeles River	
	1 - 4.75 mm	>4.75 mm	1 - 4.75 mm	>4.75 mm	1 - 4.75 mm	>4.75 mm
November 22, 2004 (wet)						
Handnet	< 1	2	< 1	40	< 1	< 1
Manta	< 1	< 1	< 1	81	< 1	< 1
Streambed	< 1	2	< 1	< 1	< 1	< 1
Handnet Laminar	--	--	--	--	43	13
December 28, 2004 (wet)						
Handnet	< 1	< 1	< 1	1	< 1	1
Thrownet	< 1	< 1	< 1	< 1	< 1	< 1
April 11, 2005 (dry)						
Handnet	< 1	< 1	< 1	0	< 1	1
Manta	< 1	< 1	< 1	< 1	< 1	< 1
Streambed	< 1	0	0	0	0	< 1

Table 4 presents the total count density by material type in each river, and Table 5 presents the total weight density by type in each river. The Los Angeles River in November had the greatest number of particles, with foam as the most abundant material. Foamed plastics were also the most abundant particles in the San Gabriel River on that date.

Table 4. Total Count Density (number/m^3) by Type

Coyote Creek							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.04	53.00	10.82	0.00	10.38	10.42	84.66
December 28, 2004	0.19	12.24	2.47	1.86	1.75	1.79	20.30
April 11, 2005	0.02	0.23	7.09	0.11	0.00	0.03	7.48
San Gabriel River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	17.95	177.24	208.26	0.00	11.91	36.32	451.68
December 28, 2004	0.68	19.48	9.71	3.14	0.84	3.75	37.60
April 11, 2005	0.00	0.12	0.37	0.00	0.00	0.00	0.48
Los Angeles River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.00	823.59	11,410.15	1,459.03	23.50	35.48	13,751.75
December 28, 2004	0.56	5.57	28.06	4.33	0.36	1.51	40.39
April 11, 2005	0.00	0.31	23.00	0.00	0.02	22.52	45.85

Table 5. Total Weight Density (g/m^3) by Type

Coyote Creek							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	1.72	0.06	0.01	0.00	0.00	2.11	3.89
December 28, 2004	0.40	0.15	0.00	0.04	0.00	0.01	0.61
April 11, 2005	0.00	0.01	0.01	0.00	0.00	0.00	0.02
San Gabriel River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	118.75	0.29	1.99	0.00	0.00	0.03	121.07
December 28, 2004	0.41	0.84	0.11	0.07	0.00	0.00	1.45
April 11, 2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Los Angeles River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.00	9.73	14.92	31.91	0.00	0.15	56.71
December 28, 2004	0.32	0.72	0.25	0.11	0.00	0.09	1.48
April 11, 2005	0.00	0.00	0.01	0.00	0.00	0.97	0.97

Pellets were found in both rivers, and were the second most abundant material found after expanded polystyrene in the LA River. Small plastics, 1-4.75mm diam. were the most common debris item in this study, constituting approximately 80% of all plastics sampled, but were outweighed 6 to1 by debris >4.75 mm in diameter.

Discussion

California policy defines trash as debris that is trapped by a 5 mm mesh screen (Trash TMDL). Our data confirms the abundance of plastic debris greater than 5 mm; however, our data shows that plastic particles less than 5 mm in size are far more abundant. The most common plastics found were bits of foamed polystyrene (commonly but incorrectly called Styrofoam, which is a patented insulation made by Dow Chemical Co.), followed by pre-production plastic pellets, hard plastic fragments, thin films, line, and whole items. Our findings indicate that there is a significant amount of plastic debris, which, due to its size, is not subject to regulation under current TMDLs for trash, passing our sampling stations and discharging to the estuaries.

Abundant plastic debris was found in both rivers, during wet and dry periods. The first wet period sampling in November 2004 was after a couple of rain events had moved through the area, so a lot of debris that had been collecting in the rivers since the last notable rain had already washed down the river. Also, the samples were not taken at the crest of each river's flood stage, so our estimates likely underestimate the actual storm water loading of plastic debris. The dry period sample was taken after the highest annual rainfall in over 100 years, which was the second highest annual rainfall in recorded history for this area. Again, a lot of debris had passed through the rivers before samples were taken, and there was considerable loading from the masses of filamentous algae that proliferated and broke loose along the river's course, filling sampling nets quickly and making debris separation and quantification difficult. Short deployment times may have allowed nets to miss debris present in the rivers. Nevertheless, there were substantial amounts of plastic debris in both rivers during each of the sampling events, including the Spring sampling when flow was low and algae abundant.

The highest total count density was found on the Los Angeles River on November 22, 2004, with 13,752 pieces collected in our samples. Based on data furnished by the Los Angeles Department of Public Works, the mean flow for 24 hours on the LA River on November 22, 2004 was 354,592 cubic meters near where our samples were collected. Extrapolation from our collected samples would likely underestimate the total count of debris since our sampling devices collected from a small proportion of the total river cross section. Applying the total flow to our average collected debris counts per cubic meter on that day yields the data set in Table 6. Applying the same flow total to our average weight density yields the weights for debris listed in Table 7. It is unlikely that these tables exaggerate the actual totals. With more systematic and comprehensive monitoring it should be possible to obtain a fairly complete picture of how much debris is being transported by the rivers. Such data could form a baseline to support decisions by policy makers regarding how to reduce trash and plastic entering our rivers and estuaries. Unless measures are taken to control debris less than 5 mm in diameter, billions of plastic particles per day will make their way to the marine ecosystem, where they exist in all strata of the water column[7], have been observed to be readily ingested by a wide variety of marine invertebrates[8], firmly embed themselves in the tissue of filter feeding organisms[4], and appear in the stomach contents of many species of marine fishes and birds[2].

Table 6. Average Count (number * 10^4) by Size Class in 24 hours

	Coyote Creek		San Gabirel River		Los Angeles River		Total
	1.0 - 4.75mm	>4.75 mm	1.0 - 4.75mm	>4.75 mm	1.0 - 4.75mm	>4.75 mm	
November 22, 2004	499.39	70.04	5,166.51	1,749.84	106,058.73	15,847.86	129392.37
December 28, 2004	15208.93	2133.07	2,389.07	331.97	74,830.33	8,314.48	103207.85
April 11, 2005	140.66	3.46	42.72	7.96	330.10	319.70	844.60
Total	15848.99	2206.56	7598.31	2089.76	181219.16	24482.04	233444.82

Table 7. Average Weight Density (kg) by Size Class in 24 hours

	Coyote Creek		San Gabirel River		Los Angeles River		Total
	1.0 - 4.75mm	>4.75 mm	1.0 - 4.75mm	>4.75 mm	1.0 - 4.75mm	>4.75 mm	
November 22, 2004	4.19	257.61	18.54	18,520.06	3,851.29	1,176.51	23828.20
December 28, 2004	789.35	4403.75	97.36	949.54	3,360.31	27,187.99	36788.30
April 11, 2005	3.35	0.35	0.01	0.00	0.96	136.54	141.21
Total	796.89	4661.71	115.91	19469.60	7212.57	28501.03	60757.71

Table 8. 24 Hour Average Count (N * 10^4) estimate by type.

Coyote Creek							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.27	356.48	72.78	0.00	69.85	70.06	569.43
December 28, 2004	163.91	10,451.03	2,106.26	1,591.23	1,497.28	1,532.29	17,342.00
April 11, 2005	0.26	3.94	120.51	18.90	0.00	0.51	144.12
San Gabriel River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	274.87	2,714.01	3,188.94	0.00	182.45	556.07	6,916.35
December 28, 2004	49.29	1,410.02	702.84	226.90	60.43	271.55	2,721.04
April 11, 2005	0.00	38.58	12.10	0.00	0.00	0.00	50.68
Los Angeles River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.02	7,300.96	101,148.72	12,934.01	208.32	314.56	121,906.59
December 28, 2004	1,148.64	11,463.78	57,759.41	8,915.36	743.12	3,114.51	83,144.81
April 11, 2005	0.00	4.42	324.82	0.00	2.53	318.03	649.80

Tabel 9. 24 Hour Average Weight (kg) estimate by type..

Coyote Creek							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	115.9	3.7	0.3	0.0	0.1	141.8	261.8
December 28, 2004	3,425.0	1,315.3	17.1	350.2	17.1	68.3	5,193.1
April 11, 2005	0.4	1.3	1.4	0.5	0.0	0.0	3.7
San Gabriel River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	18,183.4	45.2	304.7	0.0	0.5	4.9	18,538.6
December 28, 2004	298.2	608.0	82.5	54.2	0.6	3.5	1,046.9
April 11, 2005	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Los Angeles River							
	Whole Items	Fragments	Foam	Pellets	Line	Film	Total
November 22, 2004	0.0	862.5	1,322.6	2,828.8	0.3	13.6	5,027.8
December 28, 2004	6,690.1	14,759.4	5,125.7	2,202.6	0.2	1,770.3	30,548.3
April 11, 2005	0.0	0.1	0.9	0.0	0.0	136.4	137.5

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