Density of Plastic Particles found in zooplankton trawls from Coastal Waters of California to the North Pacific Central Gyre

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Introduction

Neuston (surface) trawls for plastic particles and debris in the North Atlantic Ocean were conducted in the 1970's[1] and in the North Pacific Ocean in the 1980's[19]. Although significant levels of plastic particulates were found, these studies failed to generate any regular monitoring program to assess plastic particulate levels in the marine environment. In response to the fact that plastic debris is increasing in the marine environment [3], Algalita Marine Research Foundation (AMRF), developed and tested protocols for monitoring this "major threat to marine life."[3] Although many studies have been done documenting quantities of plastic debris on beaches, floating on the ocean surface and found on the seafloor, the methods for conducting these studies have not been assessed to determine comparability.[3] Furthermore, plastic debris in smaller size classes is often ignored in beach cleanup[4] and ship board sighting surveys[2,5]. Since plastic debris that is not removed from the marine environment eventually degrades and breaks into small bits that take many years, decades or centuries to disappear,[6] i.e., mineralize[7], or biodegrade [8], monitoring the accumulation of this particulate matter can provide an indication of total plastic debris trends. The question: How much plastic debris is in the marine environment?, merits an answer for several reasons. Entanglement of marine mammals in derelict fishing gear and ingestion of plastics by seabirds are well documented and may contribute to the decline of these species.[3] The effects of small plastic particulates on the marine ecosystem is less well known, but plastic bits have been found to accumulate polycyclic aromatic hydrocarbons, chlorinated and legacy pesticides and other Persistent Organic Pollutants (POPs), and to contain hormonally active additives[9]. Furthermore, fish and marine invertebrates as well as seabirds have been found to ingest them.[3] This suggests that plastic particles may be considered a mimic of natural food, such as zooplankton, in marine habitats. In order to assess the potential for this to occur, AMRF, in collaboration with the Southern California Coastal Water Research Project (SCCWRP)[10], began assessing plastic particulate pollution by comparing it to the available food of a similar size class in neuston trawls. The size class sampled was greater than 333 microns in diameter, the size associated with most zooplankton. During elaboration of this methodology, it was determined that surface trawls alone were inadequate to assess the ocean's plastic particulate load[18]. According to the EPA, over half (54%) of plastic resins sold sink in seawater, 46% float, and the majority are almost neutrally buoyant (within 0.1g/mL of seawater density)[11]. When these resins are processed into products, fillers are often used which may increase (e.g., calcium carbonate, silica) or decrease (e.g., wood flour) their density[12]. In an AMRF study off Ballona Creek, which drains much of Los Angeles, CA, an epibenthic sled was used to obtain samples 20 cm above the ocean floor, and paired bongo nets were used to assess debris quantities in the water column down to 30 meters, areas of the water column which had not previously been assessed. [13]

To investigate plastic particulate distribution over a wide area of the Eastern North Pacific down to a depth of 30 meters, AMRF conducted zooplankton trawls in nearshore and offshore waters totaling over 12,000 miles aboard its chartered Oceanographic Research Vessel (ORV) *Alguita* from 1999-2004. The study area included an accumulation center for debris known as the "Eastern Garbage Patch" (roughly located in an area bounded by 135 to 155 W Lo and 35 to 42 N Lat), and most of the Hawaiian Archipelago. (Fig. 1)

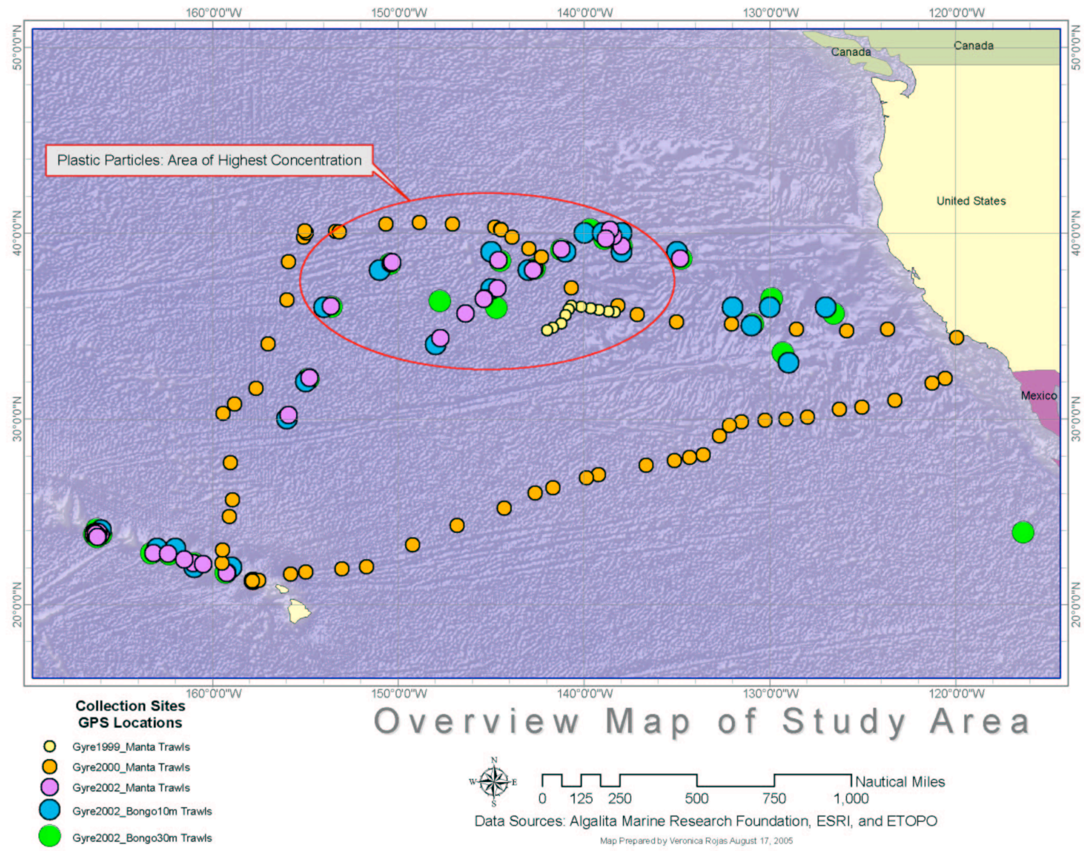

Figure 1

Methods

Surface samples were collected using a 0.9 x 0.15 m^2 rectangular opening manta trawl with a 3.5 m long, 333 micron net and a 30 x 10 cm^2 collecting bag. Mid-depth samples were collected using paired 61 cm diameter bongo nets with 3 m long, 333 micron nets and 30 x 10 cm^2 collecting bags. Bottom samples were collected using a 31cm^2 rectangular opening epibenthic sled with a 1 m long, 333 micron net and a 30 x 10 cm^2 collecting bag (Ballona study only). All nets were fitted with GO flowmeters. Samples were preserved with formalin, then rinsed and stored in isopropyl alcohol. In the laboratory, samples were placed in fresh water and floating plastic removed. A dissecting microscope was 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, 0.70, 0.50 and 0.35 mm and counted. Plastic, plankton and plant material then oven dried at 65º C for 24 h and weighed.

Publication	Date of Study	Location	Sample Depths		
Marine Pollution Bulletin 44	1999	Offshore	Surface		
	2000	Offshore	Surface		
Marine Pollution Bulletin 41	2000	Nearshore	Surface		
Marine Pollution Bulletin 49	2001	Nearshore	Surface	Water Column	Epibenthic
	2002	Offshore	Surface	Water Column	

Results

The results are presented for each study. Offshore, the 1999 survey was designed to survey an area suspected to accumulate debris, which has become known as the "Eastern Garbage Patch."(EGB) The 2000 survey sampled debris outside this area except for approximately 20 stations, which were within the EGB. The 2002 survey included trawls within the Northwest Hawaiian Islands archipelago and the EGB. This was the only offshore survey to use paired bongo nets to sample subsurface waters. (see map) The 2000 offshore survey had the lowest average surface density of plastic particles over the entire study area at 0.43 pieces/m^3. This is consistent with the trawls falling mostly outside the EGB. The 2002 survey found an average of 1.52 pieces/m^3 at the surface. The 1999 survey had the highest surface density offshore at 2.23 pieces/m^3. Both nearshore surveys, conducted in 2001, were designed to assess land based sources of debris by sampling before and after rain events. The first was located near the mouth of the San Gabriel River, which drains southern Los Angeles and northern Orange Counties, and had the highest average density of 7.25 pieces/m^3. The second nearshore survey was conducted off Ballona Creek, which drains the west side of Los Angeles. On the surface the average density was 5.0 pieces/m^3. The Ballona survey was the only nearshore survey to obtain subsurface samples. Midwater bongo net samples off Ballona Creek averaged 3.05 pieces/m^3. The epibenthic average density was slightly higher at 3.8 pieces/m^3. All the nearshore average densities include the pre and post rain event trawl data. Offshore subsurface average densities were much less. Paired Bongo nets found plastic particulates in every trawl sample taken at 10 and 30 meters depth in the North Pacific. Both the 10 meter and 30 meter bongo net trawls yielded an average density of 0.017 pieces/m^3. This result is approximately a factor of 10^2 less than densities found at the surface.

The lowest average ratio of plastic to plankton dry weight at the surface was 5.44:1 for the 2000 survey. The 2002 survey surface ratio was 6.90:1 and the 1999 surface ratio was 6.1:1. The average ratio over all depths from the Ballona Creek study was 1.40:1 and for the San Gabriel River study was 2.5:1 plastic to plankton at the surface.

The highest ratio of plastic to plankton dry weight at any one station, 128:1, was found in the nearshore during the 2000 dry season off the mouth of the San Gabriel River. The highest ratio of plastic to plankton offshore, 112:1, was found in calm conditions northeast of Hawaii (wind 7kn) during AMRF's 2000 Gyre voyage (station 44 located 1700 nautical miles to the west northwest of Los Angeles at 40 degrees N. Latitude and 153 degrees W. Longitude). The highest count of plastic particulates in the nearshore, 60 pieces/m^3, was found at the mouth of the San Gabriel River (SGR) after a rain event in 2000. The highest count of plastic particulates offshore, 11 pieces/m^3, was found during AMRF's 2002 Gyre voyage (station 7, located 1300 nautical miles to the west of the SGR at 37 degrees N. Latitude and 144 degrees W. Longitude). A plastic to Plankton mass ratio greater than 6.9:1(the highest offshore surface average) was found near French Frigate Shoals in 2002 (20.04:1) at station 25, 23 degrees N. Lat., 166 degrees W. Long. 1800 nautical miles northeast, at station 1, 39 degrees N. Lat., 137 degrees W. Long., a plastic to plankton ratio of 16.96:1 was found. These two stations represent high plastic/plankton ratio stations with the greatest distance between them. For the three studies, ratios greater than 5.44:1 (the lowest offshore surface average) were found at 34 stations widely dispersed around and within the central gyre.

AMRF's three offshore voyages between 1999-2002 found an average of 191,457 plastic pieces per square kilometer on the surface.

Date of Study	Sample Average Density pieces/m^3			Plastic:Plankton Mass Ratio		
	Surface	Water Column	Epibenthic	Surface	Water Column	Epibenthic
1999 EGB	2.23	-	-	6.1:1	-	-
2000 Offshore & Gyre	0.43	-	-	5.44:1	-	-
2000 San Gabriel	7.25	-	-	2.5:1	-	-
2001 Ballona	5.00	3.05	3.80	1.4:1	-	-
2002 Gyre	1.52	1.52	-	6.90:1	-	-

Discussion

Whether in the deep ocean or close to shore near an urban center, and whether at the surface or in the water column down to 30 meters, plastic particulates greater than 333 microns are present. All of the samples taken during the study contained particles of plastic, and during calm conditions in the nearshore, more plastic particles were found suspended above the seafloor than near the surface.[13]

Overall, the surface had about a hundred times more particles than the depths surveyed, but the 20 meters of separation between water column samples made no difference in the densities found. Nearshore, plastic pieces suspended 20 cm above the ocean floor at 3.8 pieces/m^3 were comparable to levels found at the surface offshore.

Several factors contribute to the wide distribution of plastic particulates in the marine environment In the nearshore environment, where suspended sediments are prevalent, plastic bags and objects may accumulate sediments, making plastics that would otherwise float, sink. As soon as a plastic object enters the marine environment, it begins a fouling process which includes the creation of surface films, followed by the attachment of diatoms, algae, bryozoans, crustaceans and other organisms.[7] The exact fouling sequence and its timing varies, and is still subject to debate.[14] At different stages of fouling, the associated organisms may make the plastic object more likely to sink or float. Floating plastics that become fouled and sink below the photic zone may lose their fouling organisms when they are deprived of sunlight. The organisms may be consumed or slough off and the object may then float back to the surface. Should this fouling cycle repeat itself, a sort of 'yoyo" effect could take place, with plastics sinking and rising indefinitely[14]. Adding to the uncertainty of where to sample for plastic particulates is the fact that significant mixing can occur due to wave activity at the surface. Thompson, et al. found the same types of plastic particles and fibers to be present in both the water column and in marine sediments (benthos), which suggested that "polymer density was not a major factor influencing distribution[8].” According to a study of vertical mixing of oil droplets by breaking waves, droplets smaller than a typical 50μm threshold radius “will permanently remain in the water column[15].” Since many types of petroleum at typical SSTs for our study area are within 0.14 of the specific gravity of seawater[16], it may be that many plastic particles undergo a similar fate. Ocean currents disperse and concentrate plastic particulates in ways that need further study, especially since there is no simple dispersion model for plastic debris. Both mainland and island coasts appear to serve as sieves, sources and sinks for ocean borne plastic debris.

AMRF has taken more than 200 samples from over 15,000 miles of the North Pacific Ocean to quantify neuston plastics, however, a greater number and variety of studies is needed to assess the threat posed by ocean borne plastic particulate debris, which we show exists in all trawls down to 30 meters. No studies have been done on fish or other pelagic marine life in the deep ocean, which in many areas are now exposed to more plastic particulates by weight than available zooplankton food. Many salps and even some Valella in our trawls had plastic particles firmly embedded in their tissues, and we also found them to have ingested plastic. Further research needs to be done on microplastics in zooplankton tissue

In the offshore, calm conditions appear to allow debris to surface and increase amounts per sample, especially of the smaller size class particles, but further studies focusing on the sea state at the time of sampling need to be done in order to confirm this result. Sampling at 50 and 100 meters needs to be done to determine if greater depths continue to produce similar densities as those found at 10 and 30 meters in this study. The great depths encountered offshore in the Eastern Pacific make it difficult to quantify plastics on the ocean floor, but studies on sediments nearshore have found plastics.[8]

The issue of uniformity among methods for sampling marine debris is of increasing importance as levels of marine debris and its impacts increase. Some issues that need to be resolved are:
1) sea state and its relation to mixing of debris 2) how to sample for the presence of debris at different depths in the water column 3) how to sample for different size classes of plastic debris, from the very large to the very small, since there appears to be no lower limit, and individual molecules of plastic polymers may be present.[7]

So far, no work on POPs accumulation on plastics found in the water column, or in sediments has been done. Determining the effects of ingestion of plastics both from an ecological and toxicological perspective was identified as a top research priority at a recent conference of researchers in this field.[17]

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