Marine Environmental Research 71 (2011) 41–52

Contents lists available at ScienceDirect

Marine Environmental Research

journal homepage: www.elsevier.com/locate/marenvrev

Plastic particles in coastal pelagic ecosystems of the Northeast Pacific ocean

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ARTICLE INFO

Article history:
Received 9 February 2009
Received in revised form
8 September 2010
Accepted 11 October 2010

Keywords:
Plastic particles
Fragments
Fibers
Pellets
Pelagic ecosystems
Southeast Bering sea
California current

ABSTRACT

The purpose of this study was to examine the distribution, abundance and characteristics of plastic particles in plankton samples collected routinely in Northeast Pacific ecosystems, and to contribute to the development of ideas for future research into the occurrence and impact of small plastic debris in marine pelagic ecosystems. Plastic debris particles were assessed from zooplankton samples collected as part of the National Oceanic and Atmospheric Administration's (NOAA) ongoing ecosystem surveys during two research cruises in the Southeast Bering Sea in the spring and fall of 2006 and four research cruises off the U.S. west coast (primarily off southern California) in spring, summer and fall of 2006, and in January of 2007. Nets with 0.505 mm mesh were used to collect surface samples during all cruises, and sub-surface samples during the four cruises off the west coast. The 595 plankton samples processed indicate that plastic particles are widely distributed in surface waters. The proportion of surface samples from each cruise that contained particles of plastic ranged from 8.75 to 84.0%, whereas particles were recorded in sub-surface samples from only one cruise (in 28.2% of the January 2007 samples). Spatial and temporal variability was apparent in the abundance and distribution of the plastic particles and mean standardized quantities varied among cruises with ranges of 0.004–0.19 particles/m^3, and 0.014–0.209 mg dry mass/m^3. Off southern California, quantities for the winter cruise were significantly higher, and for the spring cruise significantly lower than for the summer and fall surveys (surface data). Differences between surface particle concentrations and mass for the Bering Sea and California coast surveys were significant for pair-wise comparisons of the spring but not the fall cruises. The particles were assigned to three plastic product types: product fragments, fishing net and line fibers, and industrial pellets; and five size categories: <1 mm, 1–2.5 mm, >2.5–5 mm, >5–10 mm, and >10 mm. Product fragments accounted for the majority of the particles, and most were less than 2.5 mm in size. The ubiquity of such particles in the survey areas and predominance of sizes <2.5 mm implies persistence in these pelagic ecosystems as a result of continuous breakdown from larger plastic debris fragments, and widespread distribution by ocean currents. Detailed investigations of the trophic ecology of individual zooplankton species, and their encounter rates with various size ranges of plastic particles in the marine pelagic environment, are required in order to understand the potential for ingestion of such debris particles by these organisms. Ongoing plankton sampling programs by marine research institutes in large marine ecosystems are good potential sources of data for continued assessment of the abundance, distribution and potential impact of small plastic debris in productive coastal pelagic zones.

1. Introduction

Pollution of the marine environment by plastic debris is well documented, including records of debris accumulation in coastal sediments, in the pelagic zone from shallow coastal areas to the open ocean, and from polar seas to the tropics. In a review of the deleterious effects of plastic materials on the marine environment, Derraik (2002) concludes that plastics make up most of the marine litter worldwide and identifies the principal sources as plastic fishing gear (nylon nets and lines) discarded or lost by the fishing industry, garbage dumping at sea by vessels, and land-based plastic litter, mostly in the form of packaging materials, from densely populated or industrialized areas. Threats to marine biota are substantial and are recognized primarily as mechanical due to ingestion and entanglement, particularly by various species of seabirds, marine mammals and sea turtles (Laist, 1987, 1997;

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doi:10.1016/j.marenvres.2010.10.001

Gramentz, 1988; Weisskopf, 1988; Slip et al., 1990; Moser and Lee, 1992; Shaw and Day, 1994; Goldberg, 1995; Robards et al., 1995; Derraik, 2002; and others).

Less is known about the occurrence, abundance and effect of small plastic particles (millimeters and smaller) in oceanic pelagic ecosystems, although concern is expressed regarding the potential for their ingestion especially by planktonic organisms at the base of the marine food chain (Moore, 2008; Arthur et al., 2009). Microscopic plastic particles are widespread in the oceans and have accumulated in the pelagic zone and sedimentary habitats; primarily it seems as a result of degradation of larger items (Thompson et al., 2004) including various types of discarded product fragments and fishing net and line fibers. Another source of these particles in the marine environment is plastic resin pellets and granules used for the manufacture of plastic products (Gregory, 1978; Shiber, 1987; Redford et al., 1997; McDermid and McMullen, 2004).

Studies during the 1970s and 1980s showed that plastic particles were widespread in the surface waters of the North Pacific Ocean, and most abundant in the central and western North Pacific (Wong et al., 1974; Shaw, 1977; Shaw and Mapes, 1979; Day and Shaw, 1987; Day et al., 1990). Small plastic particles and fragments have also been documented in plankton samples from the western North Atlantic Ocean (Wilber, 1987), and in the northeast Atlantic with some evidence for increasing levels of abundance over recent decades (Thompson et al., 2004). The distribution of floating plastic debris in these oceans is related in large part to the prevailing surface circulation and winds, suggesting that plastic particles move in predictable patterns (Shaw and Mapes, 1979; Wilber, 1987; Day et al., 1990). For instance, the large, clock-wise rotating oceanic gyres of the central North Pacific and western North Atlantic are known to concentrate debris and flotsam in their centers and entrain and redistribute debris in their outer flows. Plankton sampling at the eastern edge of the North Pacific Central Gyre bears this out: Moore et al. (2001) reported high concentrations of small plastic particles in neuston (surface plankton) samples collected at eleven sites in this region. Moore et al. (2002) and Lattin et al. (2004) also recorded relatively high concentrations of plastic particles in neuston samples collected at several sites off the southern California coast, in the San Gabriel River Basin and Santa Monica Bay off Los Angeles. Gilfillan et al. (2009) examined concentration, distribution, and characteristics of plastic particles in neuston samples collected off southern California during winter research cruises in 1984, 1994, and 2007. The latter study also indicated an association between highest concentrations of particles and coastal waters adjacent to the large urban centers of southern California.

Given the identification of the North Pacific Central Gyre, and certain urban coastal sites off the U.S. west coast, as sources of plastic debris in the marine environment, it is important to investigate the abundance and distribution of microscopic plastic debris in the adjacent, productive coastal ecosystems of the Northeast Pacific. To this end, a pilot study was developed to investigate the distribution and abundance of plastic particles in plankton samples collected routinely as part of the National Oceanic and Atmospheric Administration's (NOAA) ecosystem surveys in the Northeast Pacific. The guiding hypothesis is that plastic particles are likely to be ubiquitous in the ecosystems off U.S. Northeast Pacific coasts, primarily in the surface layer of the ocean. Furthermore, such plastic particles are hypothesized to be composed primarily of the degradation products of discarded consumer items, with highest concentrations occurring in coastal regions adjacent to urban environments.

In collaboration with NOAA's Alaska Fisheries Science Center in Seattle, Washington, and Southwest Fisheries Science Center in La Jolla, California, plankton samples were collected during routine surveys in the Southeast Bering Sea and off the U.S. west coast, primarily off southern California, during 2006 and January 2007. The purpose of the present study was to 1) document the abundance, distribution, type and size of plastic particles in the above NOAA ecosystem survey areas, 2) consider the potential for using such large-scale plankton monitoring programs for assessing the occurrence of plastic particles in the pelagic environment, and 3) use this information to contribute to the development of further studies for research into the incidence, persistence and impact of microscopic plastic debris in marine pelagic ecosystems.

2. Methods

2.1. NOAA plankton sampling programs

The National Marine Fisheries Service (NMFS) of NOAA regularly samples plankton as part of its Ecosystem Survey programs in U.S. ocean waters (O'Brien, 2005). These regional surveys include routine measurement of zooplankton displacement volumes (wet mass of the plankton) as well as zooplankton composition and abundance data. Zooplankton samples collected in 2006 and 2007 during research cruises of the two Northeast Pacific NOAA Ecosystem Survey programs formed the basis of this study. These Northeast Pacific programs include the Ecosystems and Fisheries-Oceanography Coordinated Investigations (EcoFOCI) program in Alaska waters, the California Current Ecosystem Survey (CCES) off the U.S. west coast, and the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program off California. EcoFOCI is a joint research program between the Alaska Fisheries Science Center (NOAA/NMFS) and the Pacific Marine Environmental Laboratory (NOAA/Office of Oceanic and Atmospheric Research/PMEL) based in Seattle. The principal goal of EcoFOCI is to determine the influence of the physical and biological environment on marine populations and the subsequent impact on fisheries in Alaskan waters. CCES is a recent research program of the Southwest Fisheries Science Center. Its primary focus is the relationship between the marine environment in the U.S. portion of the California Current Large Marine Ecosystem and its living resources, especially pelagic fishes. CalCOFI is a unique partnership of the California Department of Fish and Game, the Southwest Fisheries Science Center (NOAA NMFS), and the Scripps Institution of Oceanography. Its present focus is the study of the marine environment off California and the management of its living resources.

2.2. Research cruises and zooplankton sampling procedures

Zooplankton samples for this study were collected, as time and primary sampling programs allowed, during two EcoFOCI cruises in the Southeast Bering Sea in the spring (May) and fall (September) of 2006 (Table 1, Fig. 1), and during four CalCOFI cruises off the U.S. west coast in spring (April), summer (July) and fall (October) of 2006, and in winter (January) of 2007 (Table 1, Fig. 2). Surface zooplankton (neuston) samples were collected during all cruises whereas subsurface samples were collected during the west coast cruises only. Collection of all zooplankton samples by towed nets was quantitative and followed standard protocols for the NOAA Ecosystem Survey Programs (Kramer et al., 1972; Smith and Richardson, 1977; Moser et al., 2001; Matarese et al., 2003). The EcoFOCI program uses a Sameoto Neuston Net (Sameoto and Jaroszyinski, 1969) to collect zooplankton from the surface layer, generally the upper 10–15 cm. This sampler, used in the Southeast Bering Sea, is made of stainless steel with a mouth opening of 30 cm deep by 50 cm wide, and is designed to fish half in and half out of the water. It was towed for approximately 10 min at a vessel speed of approximately 1.5–2.0 knots, with some variation depending on sea conditions in

Table 1
Sampling cruises conducted by NOAA, spring 2006–winter 2007, during which plankton samples were collected for plastic debris analysis. All cruises were conducted during 2006 except for CalCOFI-0701.

Cruise name	Coastal region	NOAA research vessel	Sampling dates	No. plankton samples collected	
				Neuston	Sub-surface
BS-3MF06	Southeast Bering Sea	RV Miller Freeman	May 8–19	12	0
BS-6MF06	Southeast Bering Sea	RV Miller Freeman	September 8–23	10	0
CalCOFI-0604	Off Southern Vancouver Island to southern California	[a]SIO RV New Horizon	April 1–17		
		RV David Starr Jordan	April 6–7, 20–25	80	136
		RV Oscar Dyson	April 11–29		
CalCOFI-0607	Off southern California	[a]SIO RV New Horizon	July 8–24	66	74
CalCOFI-0610	Off southern California	[a]SIO RV Roger Revelle	October 21–November 5	66	75
CalCOFI-0701	Off southern California	RV David Starr Jordan	January 12–February 1	71 (37 processed)	79 (39 processed)
Total number of samples processed for plastic debris particles				271	324

[a] Scripps Institution of Oceanography Research Vessel.

order to maintain proper skimming action. The Manta net (Brown and Cheng, 1981), used by the CalCOFI program to collect neuston samples, was used for all the U.S. west coast neuston samples in this study. It consists of a rectangular aluminum frame with a mouth opening of 15.5 cm deep by 86 cm wide. Deployment and towing procedures for the Manta sampler were similar to those for the Sameoto sampler except that total tow time for the Manta was approximately 15 min. The 0.505 mm mesh nylon nets of both samplers are suitable for sampling macrozooplankton and debris items greater than or equal to 0.5 mm in size. After retrieval of a neuston sample, the nets were carefully rinsed from the exterior to assure that all plankton and debris were washed into the cod end. Contents of the cod end were concentrated into a sample jar and preserved with a 5% formalin solution buffered with sodium borate. A calibrated flowmeter was fitted in the mouth of each sampler to measure the volume of water sampled during each tow, and the flowmeter readings were converted to cubic meters of water filtered. The debris measurements were standardized to amount per cubic meter of seawater, for each sampling station.

During the CalCOFI cruises, sub-surface plankton samples were collected using the CalCOFI Bongo sampler, comprised of a pair of circular, 71 cm diameter aluminum frames, connected to a central axle (McGowan and Brown, 1966; Smith and Richardson, 1977), and to which a calibrated flowmeter and a pair of 0.505 mm mesh nylon plankton nets were attached. The bongo tow was a double oblique haul to 212 m depth, or to 15 m from the bottom in shallow areas. Hauls were made at a ship speed of 1.5–2.0 knots. The net was lowered to ~212 m depth by paying out 300 m of wire at 50 m/min. After fishing at depth for 30 s, the net was retrieved at 20 m/min. On retrieval the Bongo nets were washed down and the sample from the starboard net was preserved in 5% formalin buffered with sodium borate. The port net sample was kept for biological studies and preserved in tris-buffered 95% ethanol. The starboard net sample from each tow (pair of nets) was used for analysis of plastic debris. As for the neuston samples, debris measurements were standardized to amounts per cubic meter of seawater, based on the total volume of water filtered by the net during each individual tow.

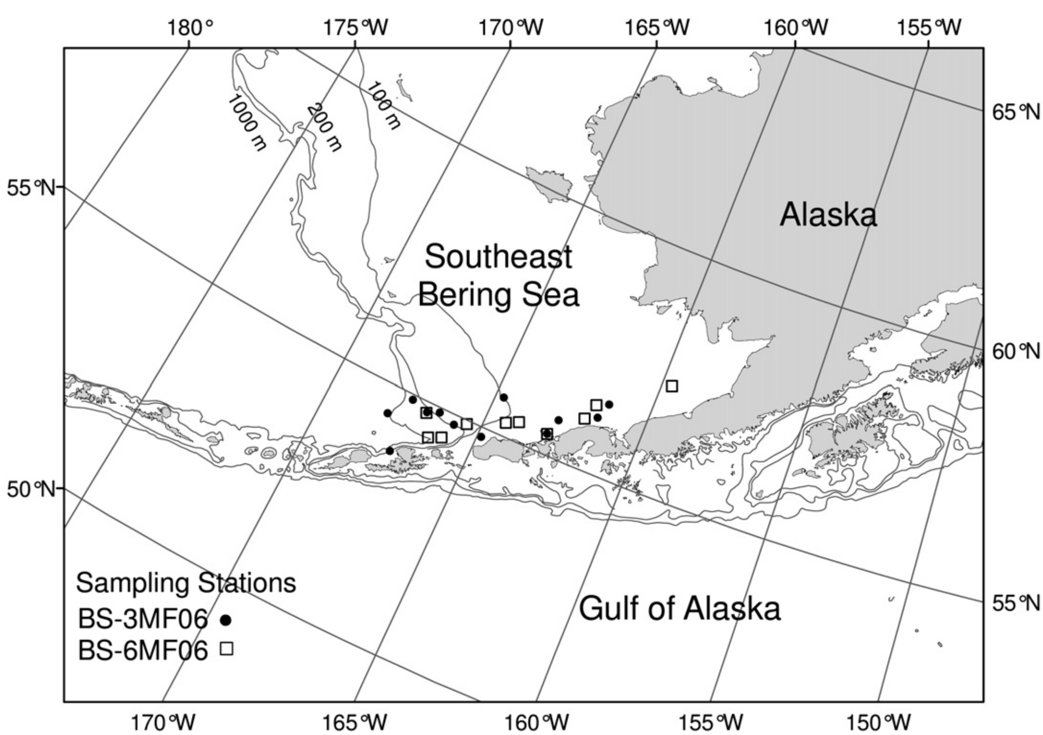

Fig. 1. Sampling area in the Southeast Bering Sea showing positions of neuston sampling stations during Cruises BS-3MF06 (May 2006) and BS-6MF06 (September 2006).

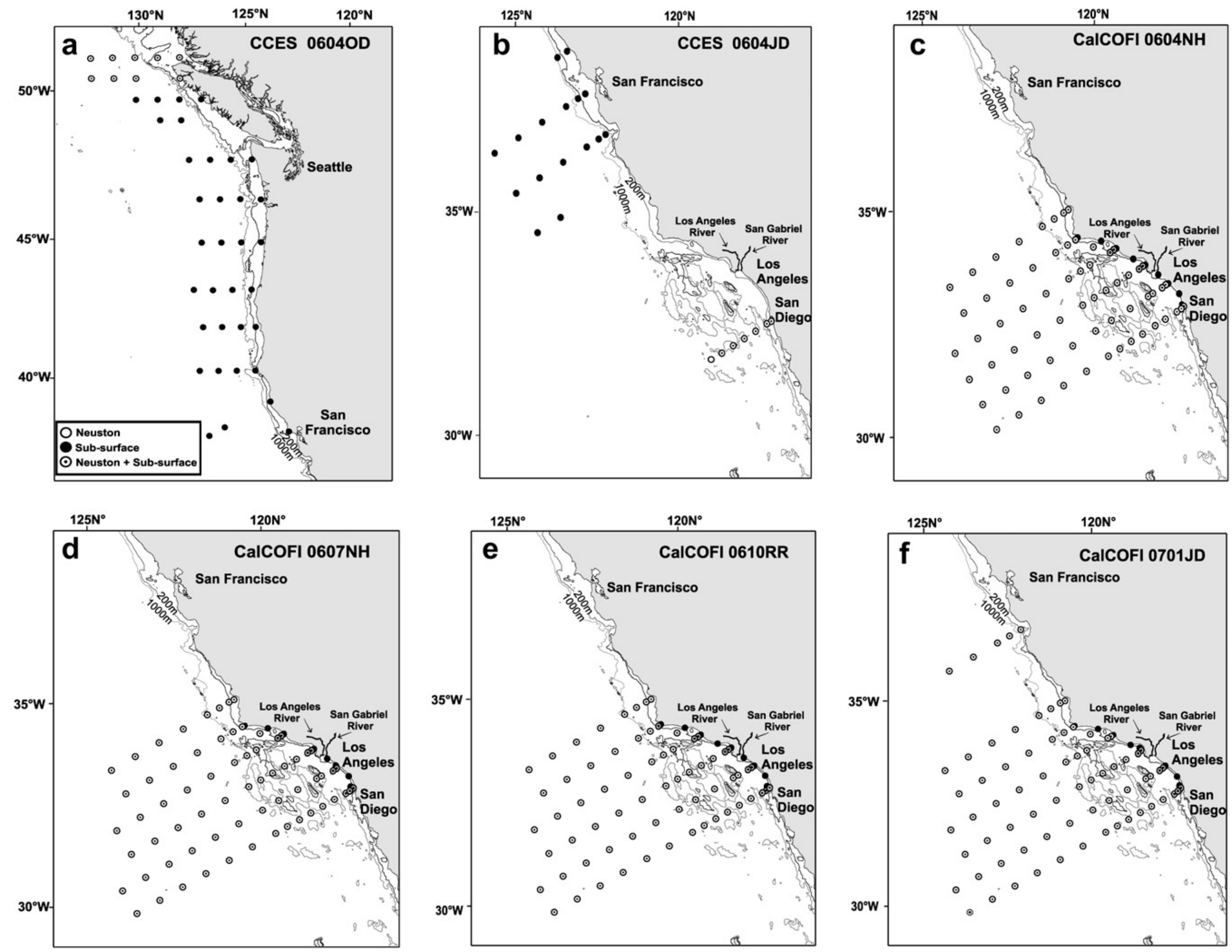

Fig. 2. Sampling area off the U.S. west coast showing positions of neuston and sub-surface plankton sampling stations during (a) Cruise CCES-0604 (April 2006) in the northern region of the California Current off Washington and Oregon; (b) Cruise CCES-0604 (April 2006) off California; (c) Cruise CalCOFI-0604 (April 2006) off southern California; (d) Cruise CalCOFI-0607 (July 2006) off southern California; (e) Cruise CalCOFI-0610 (October 2006) off southern California; and (f) Cruise CalCOFI-0701 (January 2007) off southern California.

2.3. Sample analyses

The zooplankton samples were processed at the NOAA Southwest Fisheries Science Center's (SWFSC) Ichthyoplankton Laboratory in La Jolla. Sorting was carried out with 6× magnification using a Wild M-5 binocular dissecting microscope. All debris items were removed from each sample and placed in a labeled container for subsequent identification and analysis of plastic content. Following standard CalCOFI research procedures, the remaining plankton were processed to determine displacement volume as an indirect estimate of wet biomass (Kramer et al., 1972), fish eggs and larvae were removed and stored at SWFSC's Ichthyoplankton Laboratory, and the remainder of the samples was archived at the Scripps Institution of Oceanography Pelagic Invertebrates Collection.

Debris samples were sent for analysis to an analytical chemistry laboratory (Impact Analytical in Michigan www.impactanalytical.com) that has resources and expertise in the area of plastics analysis, including spectroscopy and a polymer library. Identification, enumeration, and evaluation of the debris particles were carried out by expert staff at this laboratory, beyond the level practical at the SWFSC. Samples were examined visually using optical microscopy to determine the nature of the debris particles. The particles were initially divided into two main types, plastic and non-plastic, with the non-plastic component including a variety of debris types such as paint coatings, metal shavings, wood fragments, mineral particles, and marine biological debris (e.g. shell fragments, animal parts, plant material). Subsequent analysis was confined to the plastic component. Classification of debris components as plastic was confirmed by analyst experience including knowledge of morphological and physical response properties. In addition, the few instances where visual inspection did not identify with certainty that a particle was plastic (21 particles total), Fourier Transform Infrared (FTIR) spectroscopy was used to determine composition. This FTIR process included reference to an infrared library database to evaluate the spectra of the particles for classification as plastic or other material.

For each sample, the plastic particles were oven dried at 110 °C for 10 min, and dry mass was determined and recorded in grams to the nearest 0.0001. Subsequently, the mass of plastic particles for each sample was standardized according to the volume of water filtered by the sampling gear, and recorded as dry mass in mg/m^3 of seawater. Plastic particles were further analyzed and assigned into three plastic product types: consumer product fragments, fishing net and line fibers (polypropylene strands), and industrial raw material pellets; and five size categories based on length measurements of the longest dimension of each particle: <1 mm, 1–2.5 mm, >2.5–5 mm, >5–10 mm, and

>10 mm. Particle counts for each of these product types and size categories were converted to number of particles per cubic meter of seawater for each of the neuston and sub-surface samples collected.

3. Results

3.1. Plastic debris mass, abundance, and composition

The non-standardized, dry mass of plastic particles collected from the 595 samples processed from the six research cruises totaled 1.45 g (1450 mg). This plastic material was well distributed among samples in both survey regions, primarily in the surface (neuston) samples (Table 2, Appendix Tables 1–7, Fig. 3a), and consisted mostly of product fragments with resin pellets least abundant (Fig. 3b). The percentages of neuston samples that contained plastic particles were 25% and 40% for the spring and fall Bering Sea cruises respectively, 8.75% for the spring CCES/CalCOFI cruise, and 66–84% for the summer, fall and winter CalCOFI cruises. The mean survey values for concentration of particles in the neuston ranged from 0.004 to 0.19/m^3, and for mass 0.024–0.209 mg/m^3. Occurrence, abundance and mass of plastic debris in neuston samples from the spring CalCOFI cruise (off southern California) seemed anomalously low relative to the other cruises. A re-examination of these plankton samples, however, did not yield any further plastic material. The winter CalCOFI cruise yielded the highest mean values of concentration and mass of plastic debris. Plastic particles were not recorded in any of the sub-surface samples from the 2006 spring, summer, and fall cruises, whereas 28% of the sub-surface samples collected during winter 2007 yielded low mean concentrations and mass of plastic particles.

There was no statistically significant difference in particle concentrations or mass between the spring and fall Bering Sea Cruises (Mann–Whitney non-parametric tests, $p = 0.51$ and 0.46 respectively). Multiple comparisons among the CalCOFI cruises off southern California (northerly CCES-0604 stations removed) revealed significant differences in all cases (Kruskal–Wallis non-parametric tests, $p < 0.001$) except between the summer and fall cruises ($p > 0.05$). A re-run of this multiple comparison test without the seemingly anomalous data from the spring 2006 cruise did not change the results for the summer, fall and winter cruises. Statistical comparisons between the Bering Sea and CalCOFI collections were carried out by comparing data from the spring and fall cruises separately in order to avoid any potential influence from seasonal variation in particle distribution and abundance. Particle concentrations and mass were significantly different between the spring cruises BS-3MF06 and CalCOFI-0604 (Mann–Whitney non-parametric tests, $p = 0.001$), although the lower values for the southern California survey seemed anomalous compared to the summer, fall and winter data for this area.

There was no significant difference between concentrations and mass of plastic for the fall cruises BS-6MF06 and CalCOFI-0610 ($p = 0.85$).

3.2. Size distribution of plastic particles

Product fragments were primarily less than 2.5 mm in size in all samples (Fig. 4). Fishing net and line fibers accounted for most of the particles >5 mm in the neuston samples, with slightly elevated levels of abundance in the Bering Sea relative to the CalCOFI samples. Resin pellets were distributed relatively evenly across the size ranges under 10 mm, especially for the west coast cruises. For the CalCOFI neuston samples (accounting for most of the debris data), there is a trend of increasing abundance in plastic fragments with decreasing particle size (Fig. 4b). Although some of the particles in the <1 mm size category were <0.5 mm, they represent only an incidental retention in the 0.505 mm mesh plankton nets.

3.3. Plastic debris distribution patterns

Plastic particles occurred at both shallow and deep water stations along the Alaska Peninsula in the Bering Sea (Fig. 5), but given the limited sampling and the very low values recorded, it is difficult to discern any meaningful distribution patterns for this region. It is noteworthy, however, that both in the spring and the fall, no plastic particles were recorded at the shallowest stations furthest to the east along the Alaska Peninsula.

The incidence of plastic debris in neuston samples during the spring CCES/CalCOFI-0604 cruise was restricted to four of the northernmost stations off Vancouver Island (Fig. 6a), and three of the southernmost stations off southern California (Fig. 6b). During the 2006 summer and fall cruises off southern California, plastic debris occurred more consistently at the coastal and outermost stations than in the central area of the sampling grid, with highest standardized mass associated with some of the deepest stations in the oceanic zone (Fig. 6c and d). Plastic levels in the neuston peaked during the winter CalCOFI-0701 cruise (Fig. 6e) with occurrence at most stations, and highest levels recorded at the southern-most coastal stations off Los Angeles and San Diego (Figs. 2f and 6e). Although levels of occurrence, concentrations and mass of plastic were very low, it is significant that plastic particles were present in some of the sub-surface plankton samples collected during this winter cruise (Fig. 6f) but absent from the spring, summer and fall cruises.

4. Discussion

Results from this study confirm the hypothesis that small plastic particles are ubiquitous in the surface layer of the ocean in the highly productive ecosystems of the southeast Bering Sea and the

Table 2
Summary statistics for plastic debris data collected from neuston and sub-surface samples during all cruises. Mean and standard error values (in parentheses) are given for concentration and mass of plastic debris particles.

Cruise	BS-3MF06	BS-6MF06	CCES/CalCOFI-0604	CalCOFI-0607	CalCOFI-0610	CalCOFI-0701
Neuston samples:						
Number of samples processed	12	10	80	66	66	37
Percentage of samples with plastic debris	25.000	40.000	8.750	81.250	66.670	83.780
Mean concentration of plastic particles (no./m^3)	0.017 (±0.010)	0.072 (±0.041)	0.004 (±0.002)	0.058 (±0.006)	0.043 (±0.006)	0.190 (±0.088)
Plastic debris mean mass (mg/m^3)	0.040 (±0.034)	0.080 (±0.033)	0.024 (±0.014)	0.104 (±0.036)	0.033 (±0.012)	0.209 (±0.087)
Sub-surface samples:						
Number of samples processed			136	74	75	39
Percentage of samples with plastic debris			0.000	0.000	0.000	28.210
Mean concentration of plastic particles (no./m^3)			0.000	0.000	0.000	0.004 (±0.001)
Plastic debris mean mass (mg/m^3)			0.000	0.000	0.000	0.014 (±0.010)

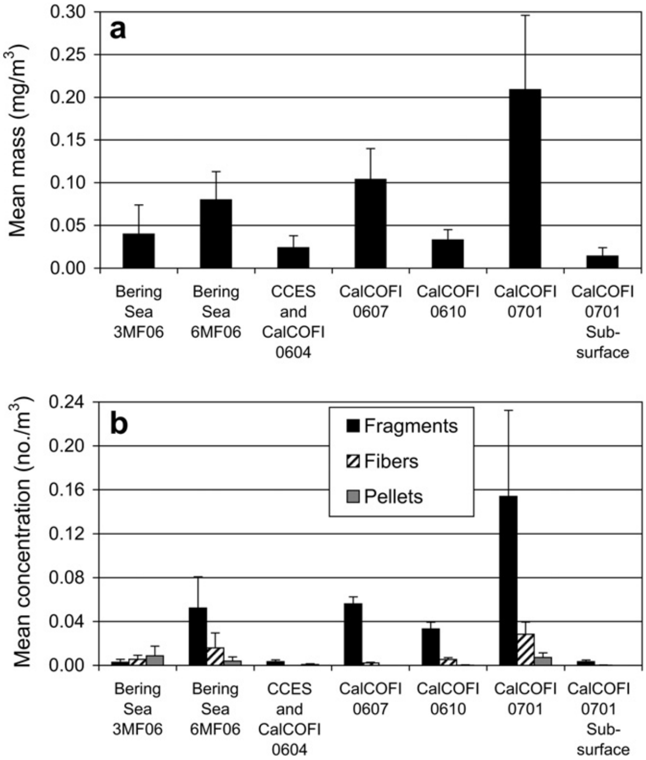

Fig. 3. Mean and standard error of (a) mass (mg/m^3), and (b) concentration (no./m^3) of plastic particles among research cruises and sampling gear. Concentrations of particles are divided into three composite categories; product fragments, fishing net and line fibers, and raw material industrial pellets.

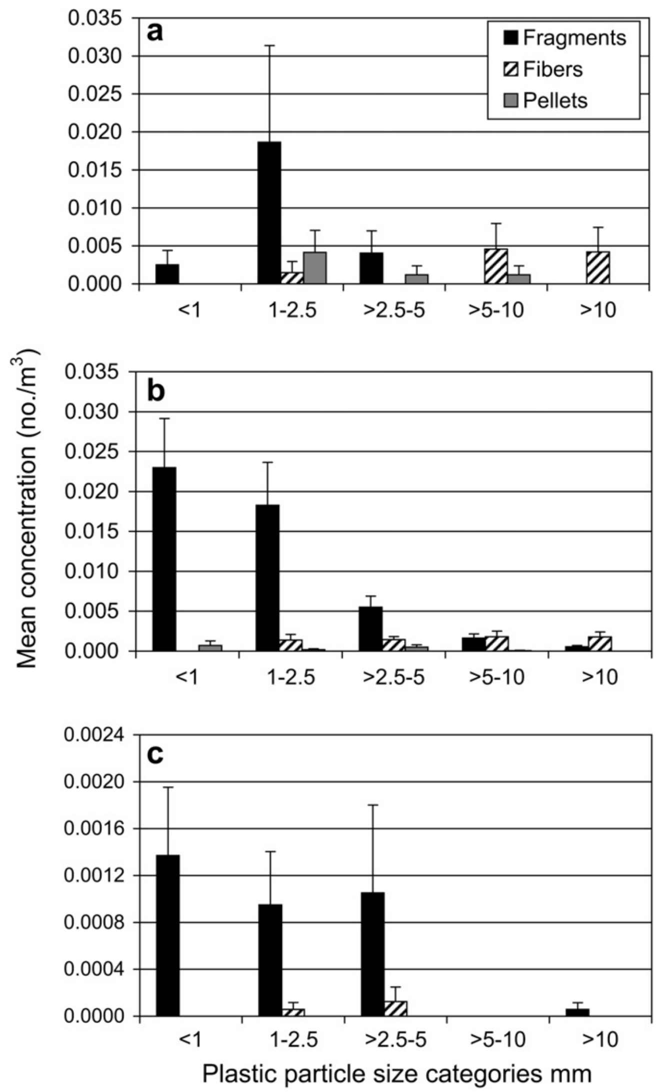

Fig. 4. Size distribution of plastic particles among composite categories showing mean concentrations (no./m^3) and standard errors for (a) neuston samples combined for both cruises in the Bering Sea, (b) neuston samples combined for all four CalCOFI (and spring CCES) cruises, and (c) sub-surface samples for Cruise CalCOFI-0701.

California Current region. The different composite types of these particles are comparable to the categories of plastic documented in previous surface plankton collections in deep water and coastal regions of the North Pacific Ocean, including plastic product fragments, fishing net and line fibers, and raw material plastic resin pellets (Wong et al., 1974; Shaw, 1977; Shaw and Mapes, 1979; Day and Shaw, 1987; Day et al., 1990; Moore et al., 2001, 2002; Lattin et al., 2004; Yamashita and Tanimura, 2007). The relative proportions of the categories are also similar to those previously documented with plastic product fragments comprising the highest proportion of total particles, and plastic resin pellets the least. The absence of plastic particles from all sub-surface samples except a small portion of those collected during winter off southern California supports the prevailing understanding that most plastic debris particles >0.5 mm in size are concentrated near the ocean surface due to their buoyancy in seawater. Lattin et al. (2004) found small plastic particles of a similar size range to those collected in this study in sub-surface plankton samples collected near shore off southern California in association with urban runoff, and they observed enhanced quantities after a late winter storm event. Winter conditions of higher turbulence in the water column, especially in coastal waters, are likely conducive to the mixing of debris particles into the water column from the surface or sediments and may explain the restriction of sub-surface particles to winter samples in this study. Microscopic plastic fibers (~20 μm in diameter) have been found in archived sub-surface samples from Continuous Plankton Recorder collections in the Northeast Atlantic (Thompson et al., 2004) thus indicating the need for investigations of a broad size spectra of plastic particles throughout the water column in pelagic ecosystems.

The standardized quantity of plastic debris, expressed as number and mass (mg) of particles per cubic meter of water sampled, was low for both sampling areas relative to previous studies in high debris accumulation zones in the Northeast Pacific. Average levels recorded in surface samples in this study (0.024–0.209 mg/m^3) were substantially lower than the average levels reported for 0.333 mm mesh Manta net surface samples at the eastern edge of the North Pacific Central Gyre (34 mg/m^3) by Moore et al. (2001, 2002), and from the San Gabriel River basin (2 mg/m^3) and in Santa Monica Bay (3 mg/m^3) off the southern California coast (Moore et al., 2002; Lattin et al., 2004). Our data and that of Gilfillan et al. (2009) suggest that the plastic particle debris load remains relatively low in this productive coastal ecosystem where more organisms are likely to be affected, as compared with the less productive open ocean ecosystem in the North Pacific Central Gyre. The average concentrations and mass of plastic particles recorded in the Southeast Bering Sea ecosystem were comparable to the levels recorded for the CalCOFI cruises, the former area representing a more pristine environment, not in close proximity to urban sources of pollution or known offshore debris accumulation zones.

It is not possible to conclude from the limited sampling in this study whether the plastic particles in the Southeast Bering Sea neuston samples originated from the nearby coastal zone or were transported long distances by ocean currents. Sources of plastic

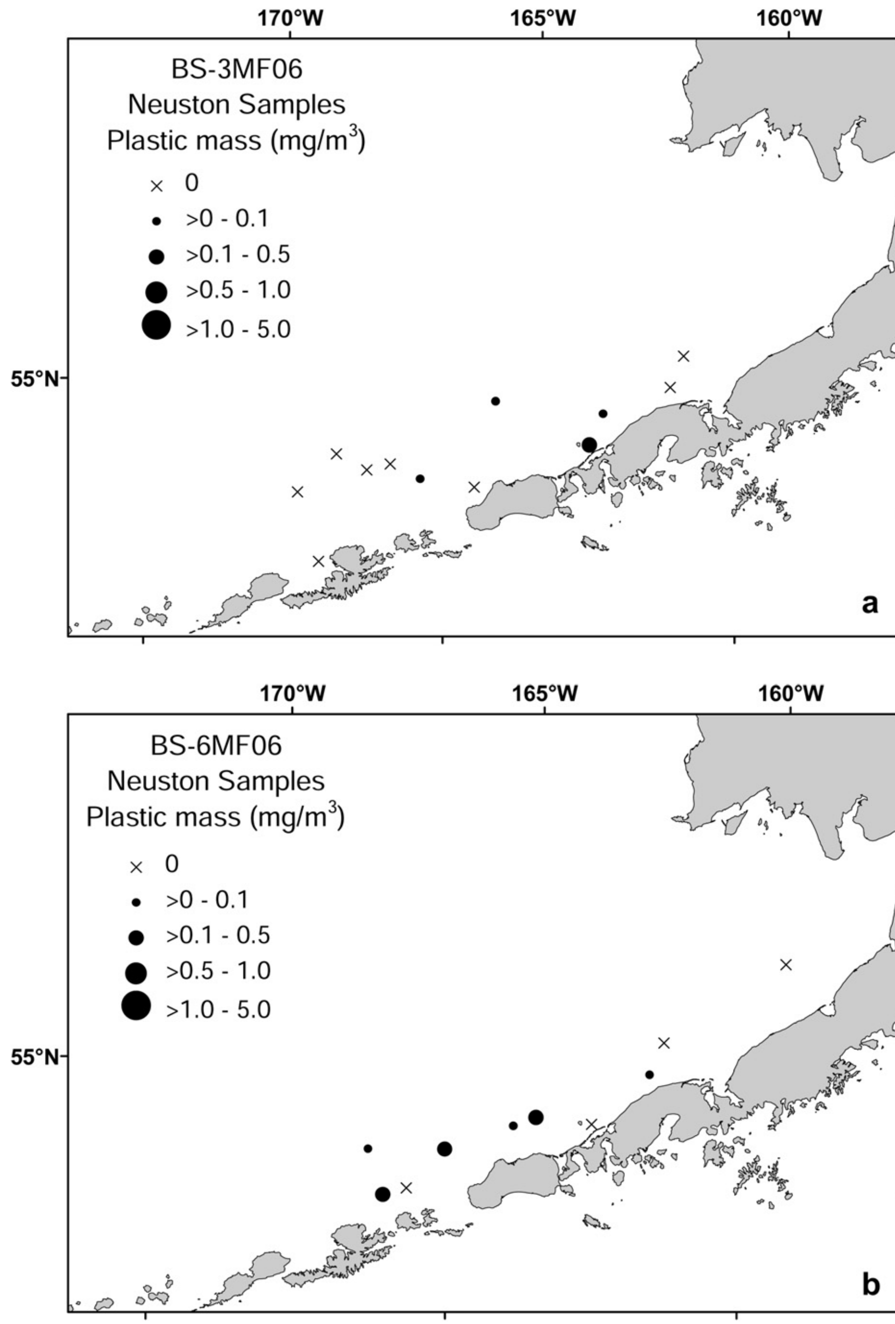

Fig. 5. Distribution of plastic particles by mass (mg/m^3) among neuston samples collected in the Southeast Bering Sea during (a) May 2006, and (b) September 2006.

debris in this region may include coastal areas along the Alaska Peninsula as well as oceanic regions to the west that could transport debris particles to the continental shelf through the easterly flowing Aleutian North Slope Current (Stabeno et al., 1999), or from the south by transport from the Gulf of Alaska through ocean passes along the Aleutian Island chain (Schumacher and Stabeno, 1998). Distribution patterns observed in the CalCOFI sampling region give us some hint of potential sources and transport of plastic particles in the California Current ecosystem. The association of highest quantities of plastic particles with the southern-most coastal stations of the sampling grid, especially during winter, reflects the likely impact of debris input from the most industrialized urban areas of the California Coast. During the summer and fall cruises, highest quantities of plastic debris were also observed at the outermost sampling stations suggesting an oceanic source for these particles. It is possible that the southerly flowing California Current may be a source of oceanic debris particles. The California Current is the eastern boundary current of the North Pacific Central Gyre (Lynn and Simpson, 1987) that is known to entrain high levels of debris at convergence zones in its outer flow (Pichel et al., 2007). It is also possible that during the summer and fall, complex features of offshore circulation of the California Current, including an equatorward jet and associated fronts, meanders and eddies (Strub and James, 2000), may contribute to the retention and accumulation of debris particles at certain offshore locations.

Although particle abundance was significantly different between all CalCOFI cruises except for the summer and fall comparison,

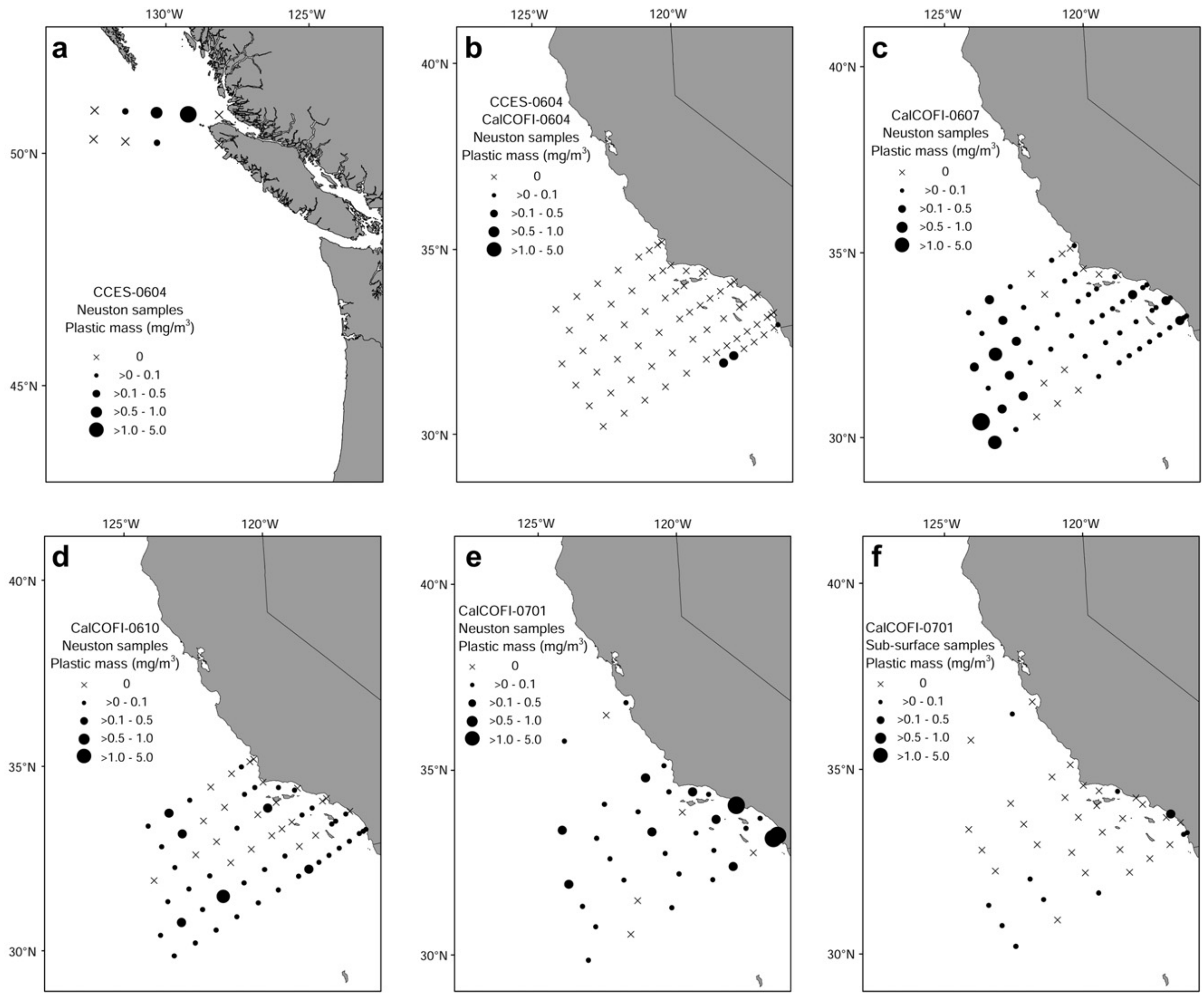

Fig. 6. Distribution of plastic particles by mass (mg/m^3) among neuston samples collected off (a) northern Vancouver Island and (b) southern California during April 2006, and off southern California during (c) July 2006, (d) October 2006, and (e) January 2007; and among (f) sub-surface samples collected off southern California during January 2007. For January 2007 (e and f), sample distribution is shown only for the samples processed for mass of plastic particles, i.e. a subset of all samples collected (Table 1, Fig. 2f).

repeated surveys during each season are needed in order to accurately assess seasonal variation in abundance and distribution patterns. It is clear that further investigation is needed regarding the occurrence, distribution and transport of plastic particles in relation to prevailing meteorological and oceanographic conditions in both sampling regions. It would be particularly useful to utilize the new generation of ocean circulation models to better understand potential sources of plastic debris particles and subsequent distribution dynamics in different oceanographic regions.

Given that the plastic debris particles observed in plankton samples are primarily the degradation products from larger articles of discarded plastic (Barnes et al., 2009), it is likely that the particles encountered in this study continue to fragment and degrade to smaller and smaller particles ($\ll$0.5 mm). The predominant trend of increasing abundance in plastic fragments with decreasing particle size in neuston samples from this study seems to bear this out. A similar inverse relationship of abundance to particle size was observed by Gilfillan et al. (2009) in the CalCOFI survey area, indicating that the true underlying size distribution of plastic particles is not sampled adequately by the larger mesh zooplankton nets. Barnes et al. (2009) notes that irrespective of global trends in accumulation of plastic debris (stable, increasing, and decreasing trends have all been reported) the average size of plastic particles in global environments seems to be decreasing, while abundance of such particles is increasing due to continuous fragmentation. Accumulation of microscopic plastic fragments ($\sim$0.02 mm and larger) in the pelagic environment was assessed by Thompson et al. (2004) in samples taken along two historical towing routes of the Continuous Plankton Recorder (mesh size 0.28 mm) in the Northeast Atlantic. Although low ($<$0.1/m^3 of seawater), the mean concentration of microscopic plastic fragments increased in these samples from the 1960s through the 1990s. A similar scenario of increasing accumulation of these tiny fragments of plastic in the pelagic environment is likely in the North Pacific Ocean, and other global oceanic regions where plastic debris accumulation and degradation continues, and merits further investigation.

Attempts have been made to assess the potential for ingestion of plastic particles by marine planktonic filter feeders by measuring the relative abundance and mass of neustonic zooplankton and plastic in surface waters of the Northeast Pacific (Moore et al., 2001, 2002; Lattin et al., 2004). This approach of presenting ratios of plastic debris dry mass to zooplankton dry mass, however, is inappropriate for such an assessment as zooplankton production and abundance varies enormously on a spatial and temporal scale, and zooplankton nets of different mesh sizes sample both zooplankton species and debris particles selectively. Furthermore, such ratios may be misleading as they provide no information on potential interaction between zooplankton species and plastic particles that may be co-occurring. The likelihood of ingestion will not only depend on presence and size of the particles relative to the species of interest, but also on encounter rates, and prey niche and feeding behavior of the specific organisms. Across taxonomic groups, feeding mechanisms in zooplankton are known to be variable, sophisticated and complex, and are affected by a wide array of internal and environmental characteristics and stimuli (Price, 1988). Also, studies on the trophic ecology of zooplankton species, from small filter feeders such as copepods (Teegarden et al., 2001) to the larger carnivores such as fish larvae (Pepin and Penney, 1997; Llopiz and Cowen, 2009; Llopiz et al., 2010) indicate high degrees of prey selectivity in the natural environment. Rigorous scientific research is needed to investigate the potential occurrence in marine ecosystems of critical concentrations of plastic particles of various sizes, at which significant encounter and ingestion rates by diverse marine zooplankton organisms would be possible. As has been documented previously, the organisms most likely to ingest the type and size of plastic debris particles documented in this study (>0.5 mm) are marine birds, fish, and marine mammals that feed on plankton, particularly in the surface layer of the ocean where this type of debris is concentrated (Derraik, 2002). Investigations of potential ingestion of such plastic debris by zooplankton organisms could therefore focus initially on some of the larger macrozooplankton species that are known to live exclusively at, or undertake diel feeding migrations to, the surface layer of the ocean such as the neustonic larvae of certain marine fish species (Doyle, 1992; Doyle et al., 1995; Llopiz and Cowen, 2009). Recent studies examining stomach contents of larval fish species, including neustonic types, in the Loop Current of the Gulf of Mexico have not revealed any ingested plastic particles (Llopiz, pers. comm.). Such studies need to be expanded, however, to include investigations of feeding and incidence of ingestion of plastic debris (across a wide size spectrum of particles) by a diverse range of zooplankton organisms in different ocean ecosystems.

Studies that examine the co-occurrence of zooplankton and debris can yield important information on quantities and characteristics of plastic particles that may be prevalent in the pelagic habitat of different zooplankton species. In addition, stomach content analysis of such organisms from field collections could contribute to an understanding of plastic ingestion potential among zooplankton taxa. Throughout many regions of the world's oceans, continuous plankton sampling programs are undertaken by major research institutions (O'Brien, 2005). Such surveys are designed to yield statistically valid results in terms of spatial and temporal variation in abundance of a diverse range of planktonic organisms, and in many instances they would provide scientifically robust data for the assessment of debris particles in the pelagic environment. These ongoing plankton sampling programs in large marine ecosystems should be considered as sources of data for continued assessment of the abundance, distribution and potential impact of plastic debris particles in productive pelagic environments.

Acknowledgements

Funding for this study was provided by NOAA's Marine Debris Program (through the National Fish and Wildlife Foundation) and by matching funds from the American Chemistry Council. The Alaska Fisheries Science Center (Seattle) and the Southwest Fisheries Science Center (La Jolla) of NOAA's National Marine Fisheries Service are acknowledged for collection and processing of plankton samples. Scientists at the Southwest Fisheries Science Center's Ichthyoplankton Laboratory were responsible for sorting the plankton samples for debris. Ichthyoplankton (fish eggs and larvae) from the CalCOFI plankton samples are archived at the Southwest Fisheries Science Center, and the remaining portions of the plankton samples are archived at the Scripps Institution of Oceanography Pelagic Invertebrates Collection. Kevin Battjes of Impact Analytical Inc. is acknowledged for the debris analysis. We thank Mark Ohman of Scripps Institution of Oceanography for reviewing an earlier draft of this manuscript. This is contribution EcoFOCI-0755 to NOAA's Fisheries-Oceanography Coordinated Investigations.

Appendix

Table A1
Neuston station positions, plastic particle abundance and dry mass for Cruise 3MF06, Southeast Bering Sea, May 2006.

Station	Haul	Latitude	Longitude	Particle abundance (no./m^3)	Plastic dry mass (mg/m^3)
9	2	54.434	−167.960	0.0000	0.0000
12	2	53.774	−167.351	0.0000	0.0000
18	3	54.899	−167.419	0.0000	0.0000
26	2	54.799	−166.828	0.0000	0.0000
29	2	54.907	−166.438	0.0000	0.0000
35	2	54.807	−165.860	0.0326	0.0326
42	2	54.821	−164.884	0.0000	0.0000
53	2	55.728	−164.751	0.0666	0.0200
65	2	55.424	−162.947	0.1047	0.4058
67	2	55.761	−162.770	0.0263	0.0026
78	2	56.118	−161.608	0.0000	0.0000
80	2	56.457	−161.424	0.0000	0.0000

Table A2
Neuston station positions, plastic particle abundance and dry mass for Cruise 6MF06, Southeast Bering Sea, September 2006.

Station	Haul	Latitude	Longitude	Particle abundance (no./m^3)	Plastic dry mass (mg/m^3)
10	2	57.278	−159.662	0.0000	0.0000
29	2	56.345	−161.801	0.0000	0.0000
33	2	56.001	−161.990	0.0334	0.0033
41	2	55.419	−162.940	0.0000	0.0000
50	2	55.406	−163.947	0.4061	0.2031
59	2	55.286	−164.332	0.0249	0.0796
67	2	54.931	−165.479	0.1408	0.1971
76	2	54.472	−166.036	0.0000	0.0000
77	2	54.357	−166.422	0.1163	0.2714
79	2	54.790	−166.829	0.0000	0.0000

Table A3
Neuston station positions, plastic particle abundance and dry mass for Cruise CCES/CalCOFI-0604, off Vancouver Island and southern California, April 2006.

Line	Station	Latitude	Longitude	Particle abundance (no./m^3)	Plastic dry mass (mg/m^3)
−14	42.1	51.02	−132.29	0.0000	0.0000
−12.3	33.3	51.04	−131.24	0.0098	0.0822
−11.1	46.2	50.39	−132.25	0.0000	0.0000
−10.7	24.3	51.04	−130.19	0.1420	0.4907
−9.4	37.4	50.39	−131.19	0.0000	0.0000
−8.9	15.4	51.04	−129.12	0.0593	0.9454
−7.7	28.5	50.39	−130.13	0.0093	0.0009
−7.2	6.4	51.05	−128.07	0.0000	0.0000
−4.3	10.6	50.40	−128.06	0.0000	0.0000
76.7	49	35.09	−120.78	0.0000	0.0000
76.7	51	35.02	−120.92	0.0000	0.0000

(continued on next page)

Table A3 (*continued*)

Line	Station	Latitude	Longitude	Particle abundance (no./m^3)	Plastic dry mass (mg/m^3)
76.7	55	34.89	−121.20	0.0000	0.0000
76.7	60	34.72	−121.56	0.0000	0.0000
76.7	70	34.39	−122.25	0.0000	0.0000
76.7	80	34.05	−122.94	0.0000	0.0000
76.7	90	33.72	−123.64	0.0000	0.0000
76.7	100	33.39	−124.32	0.0000	0.0000
80	51	34.45	−120.52	0.0000	0.0000
80	55	34.32	−120.80	0.0000	0.0000
80	60	34.15	−121.15	0.0000	0.0000
80	70	33.82	−121.84	0.0000	0.0000
80	80	33.48	−122.53	0.0000	0.0000
80	90	33.15	−123.22	0.0000	0.0000
80	100	32.82	−123.91	0.0000	0.0000
81.8	46.9	34.28	−120.03	0.0000	0.0000
83.3	40.6	34.22	−119.42	0.0000	0.0000
83.3	42	34.18	−119.51	0.0000	0.0000
83.3	51	33.88	−120.14	0.0000	0.0000
83.3	55	33.74	−120.41	0.0000	0.0000
83.3	60	33.58	−120.77	0.0000	0.0000
83.3	70	33.25	−121.44	0.0000	0.0000
83.3	80	32.92	−122.13	0.0000	0.0000
83.3	90	32.58	−122.82	0.0000	0.0000
83.3	100	32.25	−123.49	0.0000	0.0000
83.3	110	31.91	−124.17	0.0000	0.0000
86.7	33	33.89	−118.49	0.0000	0.0000
86.7	35	33.83	−118.63	0.0000	0.0000
86.7	40	33.66	−118.97	0.0000	0.0000
86.7	45	33.49	−119.32	0.0000	0.0000
86.7	50	33.32	−119.65	0.0000	0.0000
86.7	55	33.16	−120.01	0.0000	0.0000
86.7	60	32.99	−120.35	0.0000	0.0000
86.7	70	32.66	−121.03	0.0000	0.0000
86.7	80	32.33	−121.71	0.0000	0.0000
86.7	90	31.99	−122.40	0.0000	0.0000
86.7	100	31.66	−123.07	0.0000	0.0000
86.7	110	31.32	−123.74	0.0000	0.0000
90	28	33.48	−117.77	0.0000	0.0000
90	30	33.42	−117.91	0.0000	0.0000
90	35	33.25	−118.25	0.0000	0.0000
90	37	33.19	−118.39	0.0000	0.0000
90	45	32.92	−118.93	0.0000	0.0000
90	53	32.65	−119.49	0.0000	0.0000
90	60	32.42	−119.96	0.0000	0.0000
90	70	32.08	−120.64	0.0000	0.0000
90	80	31.75	−121.32	0.0000	0.0000
90	90	31.42	−121.99	0.0000	0.0000
90	100	31.08	−122.65	0.0000	0.0000
90	110	30.75	−123.34	0.0000	0.0000
93.3	26.7	32.96	−117.31	0.0000	0.0000
93.3	28	32.91	−117.40	0.0000	0.0000
93.3	30	32.85	−117.53	0.0000	0.0000
93.3	35	32.68	−117.87	0.0000	0.0000
93.3	40	32.52	−118.21	0.0000	0.0000
93.3	45	32.35	−118.56	0.0000	0.0000
93.3	50	32.18	−118.89	0.0000	0.0000
93.3	55	32.01	−119.23	0.0000	0.0000
93.3	60	31.85	−119.58	0.0000	0.0000
93.3	70	31.51	−120.23	0.0000	0.0000
93.3	80	31.18	−120.92	0.0000	0.0000
93.3	90	30.85	−121.59	0.0000	0.0000
93.3	100	30.52	−122.26	0.0000	0.0000
93.3	110	30.18	−122.92	0.0000	0.0000
95	28	32.61	−117.20	0.0127	0.0013
95	30	32.55	−117.34	0.0000	0.0000
95	35	32.39	−117.68	0.0000	0.0000
95	40	32.22	−118.02	0.0000	0.0000
95	45	32.06	−118.36	0.0000	0.0000
95	50	31.89	−118.70	0.0347	0.1597
95	55	31.72	−119.04	0.0687	0.2383

Table A4
Neuston station positions, plastic particle abundance and dry mass for Cruise CalCOFI-0607, off southern California, July 2006.

Line	Station	Latitude	Longitude	Particle abundance (no./m^3)	Plastic dry mass (mg/m^3)
76.7	49	35.09	−120.78	0.0150	0.0045
76.7	51	35.02	−120.92	0.0000	0.0000
76.7	55	34.89	−121.20	0.0000	0.0000
76.7	60	34.72	−121.55	0.0258	0.0245
76.7	70	34.38	−122.25	0.0000	0.0000
76.7	80	34.06	−122.94	0.0313	0.0047
76.7	90	33.72	−123.64	0.0759	0.4446
76.7	100	33.39	−124.32	0.1170	0.0949
80	51	34.45	−120.53	0.0000	0.0000
80	55	34.32	−120.80	0.0233	0.0070
80	60	34.15	−121.15	0.0491	0.0012
80	70	33.82	−121.84	0.0000	0.0000
80	80	33.48	−122.53	0.0108	0.0054
80	90	33.15	−123.22	0.0501	0.3442
80	100	32.82	−123.91	0.0253	0.0013
81.8	46.9	34.28	−120.03	0.0000	0.0000
83.3	40.6	34.22	−119.41	0.0000	0.0000
83.3	42	34.18	−119.51	0.0337	0.0219
83.3	51	33.88	−120.13	0.0221	0.0122
83.3	55	33.74	−120.41	0.0399	0.0050
83.3	60	33.58	−120.76	0.0797	0.0146
83.3	70	33.25	−121.45	0.0448	0.0067
83.3	80	32.91	−122.13	0.0589	0.0506
83.3	90	32.58	−122.81	0.0366	0.1160
83.3	100	32.24	−123.49	0.2282	0.6648
83.3	110	31.91	−124.17	0.0429	0.2504
86.7	33	33.89	−118.49	0.0807	0.0438
86.7	35	33.82	−118.63	0.1099	0.0151
86.7	40	33.66	−118.97	0.1805	0.1639
86.7	45	33.49	−119.32	0.0390	0.0584
86.7	50	33.32	−119.66	0.0358	0.0090
86.7	55	33.16	−120.01	0.0802	0.0134
86.7	60	32.99	−120.35	0.0117	0.0035
86.7	70	32.65	−121.03	0.0424	0.0367
86.7	80	32.32	−121.72	0.1478	0.0131
86.7	90	31.99	−122.39	0.0435	0.0116
86.7	100	31.66	−123.07	0.1201	0.1801
86.7	110	31.33	−123.74	0.0849	0.0382
90	28	33.48	−117.77	0.0376	0.0113
90	30	33.42	−117.91	0.1189	0.4822
90	35	33.25	−118.25	0.1425	0.0311
90	37	33.19	−118.39	0.0375	0.0025
90	45	32.92	−118.94	0.1022	0.0017
90	53	32.65	−119.48	0.0596	0.0060
90	60	32.42	−119.96	0.0881	0.0101
90	70	32.08	−120.64	0.1266	0.0197
90	80	31.75	−121.32	0.0000	0.0000
90	90	31.42	−121.99	0.0000	0.0000
90	100	31.08	−122.66	0.0395	0.1917
90	110	30.75	−123.33	0.0325	0.1051
90	120	30.42	−124.00	0.1180	2.0708
93.3	26.7	32.96	−117.30	0.0386	0.0039
93.3	28	32.91	−117.39	0.0667	0.0033
93.3	30	32.85	−117.53	0.0357	0.4321
93.3	35	32.68	−117.87	0.1503	0.0205
93.3	40	32.51	−118.21	0.1211	0.0108
93.3	45	32.35	−118.55	0.0341	0.0011
93.3	50	32.18	−118.88	0.0112	0.0011
93.3	55	32.01	−119.24	0.1596	0.0053
93.3	60	31.85	−119.57	0.0842	0.0042
93.3	70	31.51	−120.25	0.0293	0.0029
93.3	80	31.18	−120.92	0.0000	0.0000
93.3	90	30.85	−121.59	0.0000	0.0000
93.3	100	30.51	−122.26	0.0000	0.0000
93.3	110	30.18	−122.92	0.0147	0.0206
93.3	120	29.85	−123.59	0.0863	0.7770

Table A5
Neuston station positions, plastic particle abundance and dry mass for Cruise CalCOFI-0610, off southern California, October 2006.

Line	Station	Latitude	Longitude	Particle abundance (no./m^3)	Plastic dry mass (mg/m^3)
76.7	49	35.09	−120.78	0.0000	0.0000
76.7	51	35.02	−120.92	0.0000	0.0000
76.7	55	34.89	−121.20	0.0163	0.0033
76.7	60	34.72	−121.54	0.0000	0.0000
76.7	70	34.39	−122.25	0.0000	0.0000
76.7	80	34.05	−122.94	0.0344	0.0034
76.7	90	33.72	−123.64	0.0245	0.1630
76.7	100	33.39	−124.32	0.0885	0.0354
80	51	34.45	−120.52	0.0000	0.0000
80	55	34.32	−120.80	0.0407	0.0112
80	60	34.15	−121.15	0.0937	0.0214
80	70	33.83	−121.82	0.0000	0.0000
80	80	33.49	−122.53	0.0000	0.0000
80	90	33.15	−123.22	0.0490	0.1971
80	100	32.82	−123.90	0.0119	0.0060
81.8	46.9	34.28	−120.02	0.0124	0.0075
83.3	40.6	34.23	−119.41	0.0000	0.0000
83.3	42	34.18	−119.51	0.0592	0.0296
83.3	51	33.88	−120.13	0.0000	0.0000
83.3	55	33.74	−120.42	0.0132	0.1126
83.3	60	33.58	−120.76	0.0000	0.0000
83.3	70	33.25	−121.45	0.0112	0.0090
83.3	80	32.91	−122.13	0.0000	0.0000
83.3	90	32.58	−122.82	0.0000	0.0000
83.3	100	32.25	−123.49	0.0233	0.0326
83.3	110	31.91	−124.17	0.0120	<0.0001
86.7	33	33.89	−118.49	0.0000	0.0000
86.7	35	33.82	−118.63	0.0000	0.0000
86.7	40	33.66	−118.97	0.0231	0.0069
86.7	45	33.49	−119.32	0.0104	0.0010
86.7	50	33.33	−119.67	0.0000	0.0000
86.7	55	33.16	−120.01	0.0000	0.0000
86.7	60	32.99	−120.35	0.0000	0.0000
86.7	70	32.66	−121.03	0.0000	0.0000
86.7	80	32.33	−121.71	0.0000	0.0000
86.7	90	31.99	−122.39	0.0780	0.0223
86.7	100	31.66	−123.07	0.0254	0.0611
86.7	110	31.32	−123.74	0.0552	0.0414
90	28	33.49	−117.77	0.0000	0.0000
90	30	33.42	−117.91	0.0413	0.0857
90	35	33.25	−118.25	0.0746	0.0064
90	37	33.19	−118.39	0.0650	0.0011
90	45	32.92	−118.94	0.0000	0.0000
90	53	32.65	−119.48	0.0000	0.0000
90	60	32.42	−119.96	0.1054	0.0105
90	70	32.09	−120.64	0.0620	0.0025
90	80	31.75	−121.31	0.0829	0.0308
90	90	31.42	−121.99	0.0462	0.7145
90	100	31.09	−122.66	0.1057	0.0007
90	110	30.75	−123.33	0.2466	0.2000
90	120	30.42	−124.00	0.0249	0.0547
93.3	26.7	32.96	−117.31	0.0271	0.0285
93.3	28	32.91	−117.40	0.0105	0.0232
93.3	30	32.86	−117.53	0.0580	0.0128
93.3	35	32.68	−117.87	0.1186	0.0079
93.3	40	32.52	−118.21	0.1148	0.0129
93.3	45	32.35	−118.56	0.0097	0.0010
93.3	50	32.18	−118.89	0.0254	0.0025
93.3	55	32.01	−119.23	0.1394	0.1445
93.3	60	31.85	−119.57	0.0529	0.0013
93.3	70	31.51	−120.24	0.1411	0.0094
93.3	80	31.19	−120.90	0.1171	0.0032
93.3	90	30.85	−121.59	0.0367	0.0110
93.3	100	30.51	−122.26	0.1043	0.0104
93.3	110	30.18	−122.92	0.0890	0.0078
93.3	120	29.85	−123.59	0.0368	0.0110

Table A6
Neuston station positions, plastic particle abundance and dry mass for Cruise CalCOFI-0701, off southern California, January 2007.

Line	Station	Latitude	Longitude	Particle abundance (no./m^3)	Plastic dry mass (mg/m^3)
66.7	50	36.77	−122.09	0.0705	0.0183
66.7	60	36.46	−122.77	0.0000	0.0000
66.7	80	35.79	−124.20	0.0145	0.0015
76.7	51	35.02	−120.92	0.0550	0.0550
76.7	60	34.72	−121.55	0.1592	0.3444
76.7	80	34.06	−122.93	0.0513	0.0205
76.7	100	33.39	−124.32	0.6818	0.2019
80	55	34.32	−120.81	0.0284	0.0313
80	70	33.82	−121.84	0.0723	0.0491
80	90	33.15	−123.22	0.0299	0.0404
81.8	46.9	34.28	−120.03	0.0332	0.1573
83.3	42	34.18	−119.51	0.0125	0.0038
83.3	55	33.75	−120.41	0.0000	0.0000
83.3	70	33.26	−121.43	0.0594	0.1040
83.3	90	32.58	−122.81	0.0717	0.0459
83.3	110	31.92	−124.15	0.6133	0.3720
86.7	35	33.83	−118.64	0.6393	1.5129
86.7	45	33.49	−119.33	0.0593	0.1467
86.7	55	33.16	−120.01	0.0152	0.0198
86.7	70	32.66	−121.03	0.0659	0.0165
86.7	90	31.99	−122.39	0.0160	0.0048
86.7	110	31.31	−123.73	0.2282	0.0742
90	30	33.42	−117.90	0.1250	0.0406
90	37	33.19	−118.39	0.0152	0.0008
90	53	32.65	−119.48	0.0174	0.0009
90	70	32.09	−120.64	0.0508	0.0118
90	90	31.42	−121.99	0.0000	0.0000
90	110	30.75	−123.33	0.0143	0.0007
93.3	26.7	32.96	−117.31	0.0000	0.0000
93.3	28	32.91	−117.40	3.1409	1.6112
93.3	30	32.85	−117.54	0.5390	2.5191
93.3	40	32.51	−118.22	0.0000	0.0000
93.3	50	32.18	−118.89	0.0342	0.2363
93.3	60	31.87	−119.57	0.0324	0.0421
93.3	80	31.18	−120.92	0.0540	0.0018
93.3	100	30.51	−122.26	0.0000	0.0000
93.3	120	29.85	−123.59	0.0179	0.0323

Table A7
Sub-surface station positions, plastic particle abundance and dry mass for Cruise CalCOFI-0701, off southern California, January 2007.

Line	Station	Latitude	Longitude	Particle abundance (no./m^3)	Plastic dry mass (mg/m^3)
66.7	50	36.77	−122.09	0.0000	0.0000
66.7	60	36.46	−122.77	0.0072	0.0002
66.7	80	35.79	−124.20	0.0000	0.0000
76.7	51	35.02	−120.92	0.0000	0.0000
76.7	60	34.72	−121.55	0.0000	0.0000
76.7	80	34.06	−122.93	0.0000	0.0000
76.7	100	33.39	−124.32	0.0000	0.0000
80	51	34.45	−120.53	0.0067	<0.0001
80	60	34.15	−121.15	0.0000	0.0000
80	80	33.48	−122.54	0.0000	0.0000
80	100	32.82	−123.91	0.0000	0.0000
81.8	46.9	34.28	−120.03	0.0000	0.0000
83.3	40.6	34.22	−119.41	0.0110	0.0005
83.3	51	33.88	−120.13	0.0000	0.0000
83.3	60	33.60	−120.75	0.0000	0.0000
83.3	80	32.91	−122.13	0.0000	0.0000
83.3	100	32.24	−123.49	0.0000	0.0000
85.4	35.8	34.01	−118.84	0.0000	0.0000
86.7	35	33.83	−118.64	0.0000	0.0000
86.7	45	33.49	−119.33	0.0000	0.0000
86.7	55	33.16	−120.01	0.0000	0.0000
86.7	70	32.66	−121.03	0.0000	0.0000
86.7	90	31.99	−122.39	0.0114	0.0014
86.7	110	31.31	−123.73	0.0023	0.0011

(continued on next page)

Table A7 (*continued*)

Line	Station	Latitude	Longitude	Particle abundance (no./m^3)	Plastic dry mass (mg/m^3)
90	27.7	33.49	−117.75	0.0488	0.4813
90	30	33.42	−117.90	0.0000	0.0000
90	53	32.65	−119.48	0.0000	0.0000
90	70	32.09	−120.64	0.0000	0.0000
90	90	31.42	−121.99	0.0124	0.0027
90	110	30.75	−123.33	0.0022	0.0096
91.7	26.4	33.24	−117.47	0.0000	0.0000
93.3	28	32.91	−117.40	0.0022	0.0001
93.3	35	32.68	−117.87	0.0000	0.0000
93.3	45	32.35	−118.55	0.0000	0.0000
93.3	55	32.02	−119.23	0.0000	0.0000
93.3	70	31.52	−120.24	0.0070	0.0002
93.3	90	30.85	−121.59	0.0000	0.0000
93.3	110	30.18	−122.92	0.0048	0.0012
93.4	26.4	32.95	−117.28	0.0248	0.0446

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