Investigation of Passive Systems for Concentrating Marine Debris

Voyage of the Kaisei
August 2009
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Many plastics that are washed or thrown into the sea and have at least a marginally lower specific gravity than sea water tend to accumulate at center points in the ocean circulation systems. One such location is the Eastern North Pacific Subtropical Gyre located roughly between Latitude 30N and 40N, Lon 140W to 160 W. Project Kaisei was organized to investigate several aspects of this gyre including mapping the density and location of the debris, the degree to which the plastic is serving as a transport mechanism for POPs, and the contamination of the food chain. The project was also charged with the task of determining the feasibility of commercially harvesting the plastic and converting it to a usable product such as diesel fuel through pyrolysis or other recycling methods.

Based on the earlier investigations of Charles Moore of the Algalita Foundation, there were several factors making any active system of collections impractical. The first is the low density of plastic per unit volume of seawater. Previous published figures give the concentration as 5114g/km. [1] Assuming that figure is roughly accurate, and assuming that two fishing trawlers were used to drag a net between them, and that the pyrolysis equipment was 70% efficient, the output of diesel fuel from pyrolysis would be on the order of 1/100 of the fuel used to gather the material. Other significant problems with nets are the destruction of plankton and other invertebrates, as well as larger fish. This is a problem both for the ecosystem and the sorting of plastic itself. At times on this cruise, the Manta Trawl would be clogged with plankton and jelly fish within 1 hour. Only a few samples have been analyzed but the ratio by wet weight of organic material to plastic ranged up to 20:1 (see table 2), a ratio that would make commercial harvest impractical and have a negative impact on the ecology of the area.

The focus of investigations on this cruise was passive systems. Four systems were tested, two of which proved to have merit. A second aspect of the investigation was determining the distribution of particles sorted into four size gradations by means of screens.
Each of the four methods will be discussed as well as the results of a preliminary experiment on sizing the particles.

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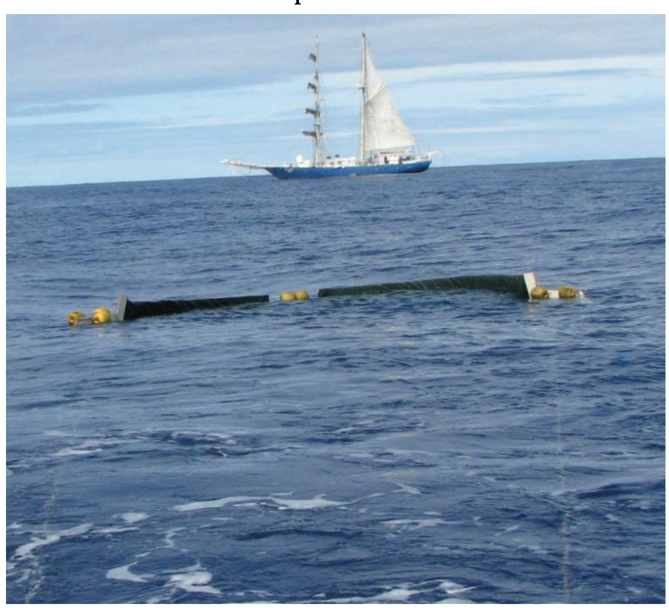
[1] Moore, C.J., Moore, S.L., Leecaster, M.K., A Comparison of Plastic and Plankton in the North Pacific Central Gyre, Marine Pollution Bulletin, Vol. 43 No 12, 2001, pp. 1296-1300.

Conceptual Basis

To capture plastic particles requires moving water past or through a gathering device that can separate the particles from the water and allow mobile life forms to escape. The simplest embodiment of this idea would be a net anchored in a zone of current so that the current passes through the fixed net. Presumably fish and other life forms would be able to swim clear of the net due to the low velocity of the current. This approach might work well in an area like the Northwest Hawaiian Islands, but the central area of the gyre which is presumed to have the greatest concentration of plastic is deep, 2,000 to 3,000 fathoms, and lacking in consistent currents.

The Sweep Trawl

Since it is known that surface currents are in fact limited to the upper zones, often less than 200m, it is possible to anchor a device to a deeper zone of the ocean that is moving in a different direction from the surface current. To test this idea we built a trawl that was inspired by the idea of marrying an oil containment boom to a trawl net. It consisted of two panels of heavy tarpaulin material, 14 feet long by 29 inches deep weighted at the bottom edge and floated at the top edge. The panels were attached on one end to a collecting net of 500microns with a rectangular opening 75cm by 73 cm and extending 3m to a cod end. The other end of each panel was attached to a plywood door angled outward, so the flow of water would hold the ends of the wings apart as in a typical fishing trawl. The apparatus was attached to a float by a 70 foot bridal. A 15 foot diameter parachute was held between 75 feet and 150 feet below the surface by a weight attached to the line connecting the parachute to the float. (See diagram 1)



The first trial took place with a southerly wind of 4 to 6 knots and current setting to the south at approximately 0.3 knots. The differential current between wind driven surface drift and current 100 feet below the surface provided sufficient flow to enable the doors to hold the mouth of the net 4 to 5 meters apart. Floating plastic was guided along the face of the "wings" and into the plankton net attached. Some plastic suspended below the surface was carried below the wings by the current escaping under the wings. Some minor adjustments were made to raise the height of the central net to prevent waves from slopping over the top and add more weight to the bottom of the doors to keep them vertical. Otherwise no major alterations were made.

Results:

The *sweep* was deployed on August 14 at 13:30 and retrieved after 1 hour for repairs as the duct tape that was used to partially secure the internal float material in the wings failed in the salt water and was replaced with stitching. The *sweep* trawl was redeployed for 6 hours and 20 minutes more. The first trial there was a 5 knot southerly wind with a current opposing the wind which created ideal conditions. During the 6h 20min trial the trawl traveled over 1.9 miles to windward as measured by shipboard GPS. When recovered, the cod end contained plastic fragments, and a small amount of organic material consisting mostly of 1mm to 2mm single celled plankton. The net dry weight of the plastic was 11.9g for a yield of 1.88g/hour.

The *sweep* trawl was deployed again on August 17 under quite different conditions. The wind was northeast between 10 and 15knots with no opposing current. During the trial of 5 hours 15minutes, the trawl moved 1.5 miles west southwest (in the direction of the wind). Two issues became apparent. First, if there was a current opposing the wind driven drift, it was deeper than the anchor we set. As a result, there was little current flowing past the doors, and the force of the waves coming from an angle to the trawl tended to push the windward door out of alignment allowing the mouth of the net to close blocking the entrance of any material into the trawl. We were unable to cure this on the water and could not stay in position to monitor the amount of time the net was closed. The resulting haul was 1.6g. Since we do not know how much of the time the trawl was functioning it is not valid to give a per hour figure for the catch. It should be noted that the there was less visible plastic in the water than on the 14th. This could be due to the increased wave agitating the surface action that churned the plastic below the surface as well as less plastic in the area.

Wingless Trawl

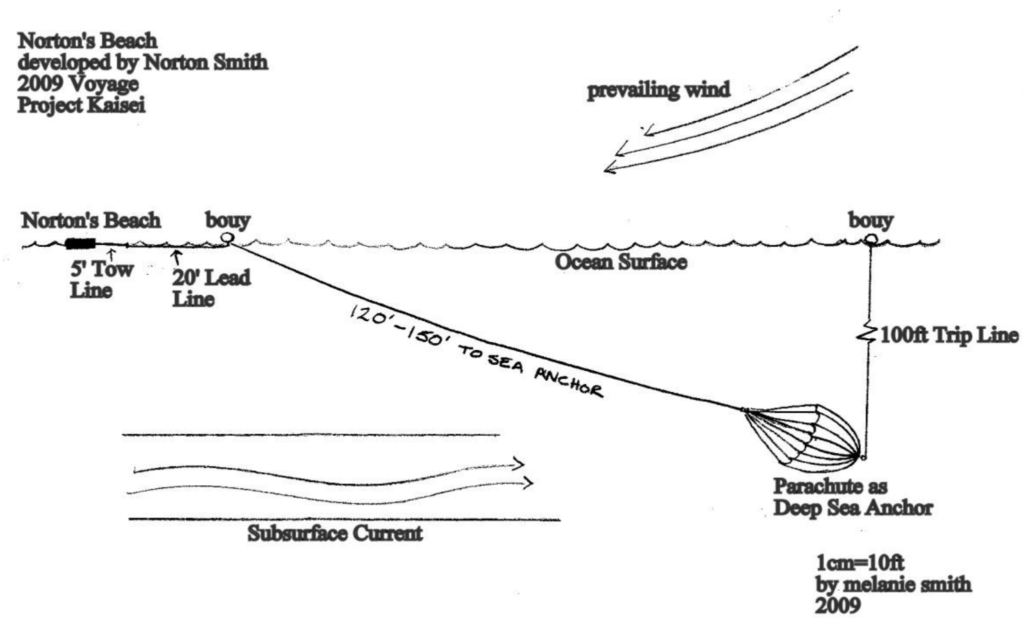
In an effort to compare the effectiveness of the wings in channeling plastic to the central net, we built an identical net (75cm by 73cm) and deployed it alongside the winged version on August 17. While the experiment was not an effective test of either system, it is worth noting that the wingless trawl only collected 0.1g of material in the same period. In other words even though the wings were ineffective for a significant portion of the 5 hours, the winged version collected over 10 times that of the wingless version. One of the concerns about using a non permeable material for the wings was that the plastic being close to neutral buoyancy would flow downward and escape under the wings of the trawl before reaching the net. Apparently this is not a significant problem.

The Beach

As an alternative to harnessing subsurface currents, the *beach* was built to mimic the natural action of waves on the shoreline which effectively deposit inanimate objects on the sand while allowing motile creatures to escape. The *beach* was formed by a sloping sheet of plywood bounded and supported by plywood sides. The sides were floated so that the upper end of the inclined plywood was roughly 3 inches above the water. A cone of nonporous fabric was fitted to the upper end of the *beach* across the width of the device fastened to the inclined plywood and to a support 8 inches above the inclined *beach* so that all the water and debris that washed over the lip of the plywood was captured and concentrated. A cod end of 500 micron mesh was fitted to the narrow end of the cone to collect the debris and let the water pass through. The *beach* was secured to a 15 foot diameter parachute positioned 20 to 40 feet below the surface as an anchor.

The *beach* was deployed on August 14 at 9:30 am and left out for 10 hours 45 minutes. The sea anchor oriented the beach into the wind so that waves broke on the incline and washed over the rim into the catchment. Very little water flowed back in the other direction resulting in a net flow through the cod end. The situation of current opposing the wind was advantageous as the *beach* moved 3.2 nautical miles to windward during the trial.

Diagram 1: The "Beach"



Results:

When the device was recovered, the extra loading from the water draining out of the net caused the cod end to detach and a significant amount of plastic was seen to float free before the cod end could be recovered. When the cod end was examined after the trial, it contained plastic but no visible life forms. This is significantly different from the results with the Manta Trawl which collected more planktonic material. The actual mass of material collected is uncertain as the cod end became detached, but 11.0 grams dry weight of plastic was recovered or 1.02g/hr. Given that up to half of the material may have been lost this number is superior to the *winged trawl* under the same conditions because the path swept by the *beach* was 1.22m or between 25% and 35% of the opening for the *winged trawl*. Thus if the sizes were equivalent, the *beach* would have harvested between 3g/hr and4 g/hr not accounting for the loss of material.

Another difference that was noted was the relative absence of life forms in the sample from the *beach*. Both devices produced samples with far more plastic than organic material by volume, but there was almost no visible life in the *beach* sample. On returning to shore and drying the samples many single celled plankton of approximately 1mm were visible, but the numbers were much less in the sample from the *beach* than the *winged trawl*. A rough approximation of the difference can be made by comparing the ratio of wet weight to dry weight for the *beach* (3.17) to that for the trawl (6.4). The ratio of organic matter in the sample may not be the neat 1:2 ratio, but there is a correlation.

The *beach* was deployed a second time along with the trawl on August 17. Without the benefit of a favorable current, the *beach* collected 4.9 g dry weight of small plastic plus a detergent bottle and another large piece of plastic. The large pieces weighed 70.8g for a total of 75.7g. The hourly rate was 0.89g/hr for just the small pieces and 13.8g/hr for the full catch. Not counting the large pieces, the results are still superior to the trawl (1.6g) which can be accounted for because the *beach* can effectively use the wave action from the stronger winds to move water through the device.

Refinements and suggestions:

One side of the *beach* was fitted with wedge shaped strips of wood to catch particles on the outflow of waves and then move them forward on the inflow. There is no numerical data as to the effectiveness of the idea, but it appeared that more water moved up the *beach* and over the lip on the side that did not have the strips. Since the plastic is floating, it was never seen being caught by the strips and my conclusion is that they are not helpful.

In following tests with more wind and larger waves, the height of the lip was adjusted but it was unclear that raising the lip in larger waves was beneficial. The higher lip reduced the amount of water that sloshed back out, but reduced the amount of water that washed in as well. On a larger model some method of adjusting the buoyancy to match wave conditions would be needed, but if the net was large enough to accommodate the larger surges of water with higher waves, the adjustment would be relatively small.

Lagoon

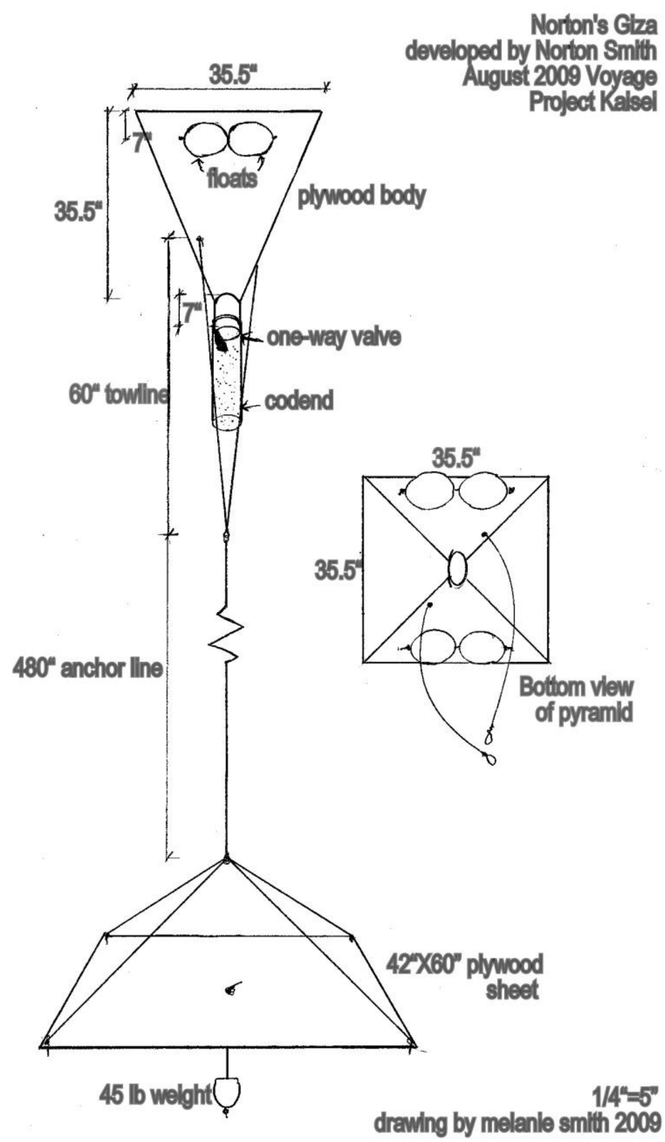
In the interest of simplicity, another design for a wave activated collection device was built. An octagon 1.4 meters in diameter was constructed out of 1 ½ inch PVC pipe. A cone of non-porous flexible material was attached to the pipe ring to collect the flow and concentrate it into a cod end. The cod end had enough weight to keep it hanging directly under the octagon float. In principal, the waves would wash over the ring, depositing the plastic in the calmer water inside the ring.

The *Lagoon* was tested on August 20 in 5 knots of wind. While there was a visible amount of water sloshing into the central area, the volume was not sufficient to allow for meaningful accumulation of plastic. Because of logistical considerations, the experiment was ended after approximately one hour.

Two issues are involved and may be solved with refinements to the geometry of the device. First, the amount of water flow was insufficient. A larger device with more mass would work better. The small unit was able to ride with the moderately sized waves, so they did not break over the ring. Larger waves occasionally did break, but their force could easily carry the plastic across the ring and out the opposite side. The second and related issue is finding a way to get the plastic to sink to the bottom of the cod end or else design the system so the catchment net is at the surface. In theory the device could be constructed to work like an omnidirectional beach.

The Pyramid:

The Device: The *pyramid* was conceived as a means of harnessing the longer period ocean swells to move water through a net in the absence of wind and current. By anchoring a rigid, floating, hollow, conical, device with the apex downward to a level ocean below the influence of the swell, the cone should be pulled under the surface by the anchor as each swell passes, then rise back to the surface. The rising cone would force water trapped in the cone downward through the apex of the cone and out through the fabric net. Since all of these devices were built on a sailing ship at sea, the simplest design was used. The cone consisted of a four sided pyramid with an aluminum tube at the apex. A flapper valve was secured to the tube so water could only flow downward into the net which was attached below the valve. The anchor consisted of a sheet of plywood offering 18 square feet of resistance and weighted with a 45 lb. lead weight. The anchor was initially secured by a 25 foot line so that the plywood was positioned horizontally directly beneath the cone.



After some adjustments to get the floatation and weight balanced the device began to function. On the first trial, it became clear that the anchor needed to be larger and deeper in order to pull the *pyramid* under the surface. This balance turns out to be fairly critical. The valve at the base enables the pyramid to act like a pump. If the device was not refilled regularly, the pumping action removed water from the inside and increased the buoyancy to the point at which the anchor no longer could submerge the pyramid. In a full scale version, some control mechanism would be required to adjust the buoyancy to match the swell.

Results:

The *pyramid* was deployed briefly then returned to the ship for modifications. A larger subsurface anchor was added and more weight was added to the anchor in order to insure that the device submerged periodically. The device was redeployed on August 20 at 13:00 hours and left for 3 hours. The anchor plane was set at 10 meters with a 45 pound weight. The device floated at the surface and was repeatedly filled with water as waves washed into it and were pumped through the net by the rising and falling of the swell. The amount of plastic that was collected was negligible at 0.1g. However, the *beach* was also deployed at the same time and only captured 0.3g. Since little plastic was seen in the water the poor results cannot be blamed entirely on the performance of the device but must take into account the relative absence of plastic in the area.

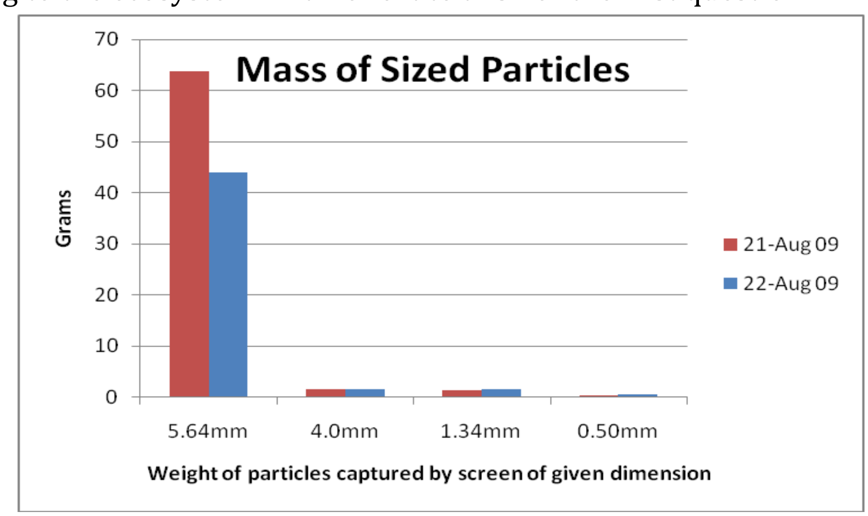
Several issues were apparent. First, the 10 meter separation between the anchor and the collector was insufficient to utilize the longer swells. The line needs to be close to ½ the wavelength of the swell which on that day was roughly 500 feet. The device is less selective than the *beach* because it takes in water from all sides and the inflow of water is not limited to the top few inches, thus it is inherently less efficient than the *beach* at separating plastic from living creatures. In theory it could make up for this by processing a greater volume of water. In order to do this, the opening to the net would need to be larger to allow more flow, and both the flotation and the anchor would need to be larger so the action of the device is more aggressive. Based on observations during the test, further experiments are warranted because of the advantage of being able to capture plastic on days with no wind and no opposing currents.

Table1

			Results for Passive Capture Systems								
	Beach										Ratio
		Position						Net wet	Net dry	Rate	wet mass
Date	Time in/out	Lat.	Lon.	Duration	Wind	Sea (ft)	Speed (kn)	weight (g)	Weight (g)	g/hour	to dry
8/14/2009	9:30	34° 47.2'N	143° 22.5'W	10hr 45min	180 °	Waves 0-1'	0.30	34.9	11	1.02	3.17
	22:00	34° 44.51'N	143° 20.6'W		0 - 5 knots	Swell 2-3'	into wind				
8/17/2009	13:00	33° 56.98N	139° 02.15W	5hr 30min	70°	wave 2'	0.28	9.8	(pieces) 4.9	0.89	2.00
	18:30	33 57.354N	139 03.90W		10-15 knots	Swell 3-5'	downwind	NA	(bottle) 70.8		
									total 75.7	13.8	
	Winged Sweep										
14-Aug	15:10	34° 45.94N	143° 20.77W		180°	Waves 0-1'	0.30	76.2	11.9	1.88	6.40
	16:40	34° 44.058N	143° 20.825W	6hr 20min	0-5 knots	Swell 2-3'	180°				
17-Aug	13:30	33° 56.98N	139° 02.15W	5hr 15min	70°	wave 2 '	0.29	5.9	1.6	0.305	3.69
	18:45	33° 57.354N	139° 03.90W		10-15 knots	Swell 3-5'	282°				
	Wingless Sweep										
17-Aug	13:30	33° 56.98N	139° 02.15W	5hr 15min	70°	waves 2'		0.1	0.1	0.019	1.00
	18:45	33° 57.354N	139° 03.90W		10-15kn	swell 3-5'					
	Pyramid										
20-Aug	15:00	37° 01.7N	140° 47.6W	4hr	NE - 5kn	<1		NA	0.1		
	19:00					swell 3'					

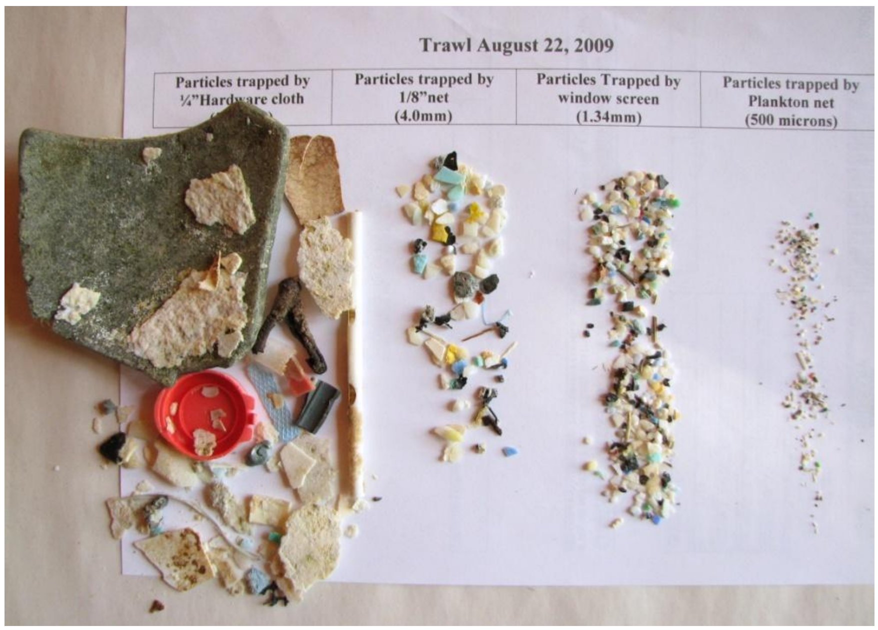
Sizing of the plastic in the gyre

The prospect of cleaning up the plastic in the ocean has two aspects. First, can any part of it be cleaned up in a way that is economically feasible? The second consideration is picking the debris that is most damaging to the ecosystem. In an effort to answer the first question we collected two samples with a manta trawl with 333 micron net then ran the sample through a stack of four sieves. The sieve material was chosen to be commercially available and inexpensive rather than for scientific precision in anticipation of using the material on a larger scale for collections. The screens



graded from ¼ hardware cloth, 1/8 minnow net, fiberglass window screen, and finally, 500 micron plankton net. The actual openings in the mesh were 5.54 mm, 4.0mm, 1.34mm and .50mm. Although the majority of plastic particles were less than ¼ inch and passed easily through the coarse screen, the aggregate mass of the particles less than ¼ inch was only 10% of the total mass captured in the trawl. Clearly two samples is insufficient, but a visual inspection of other samples tends to corroborate the results. On a larger scale a similar ratio was apparent. Though the actual weights of the macro sized plastics collected is only an estimate, it is clear that most of the mass of plastic brought back by the Kaisei is contained in pieces larger than 15cm. In fact most of the mass was in the two ghost nets brought on board.

The implications are clear. First, if the goal is to pick up as much plastic as possible with the least damage to the life forms in the area, one would collect the larger pieces only, perhaps using a 3cm or greater mesh net. Further, it would be important to locate as many ghost nets as possible which would require some form of aerial reconnaissance. In its simplest form this could be a remote camera mounted on a kite tethered to the ship. The downside of this tactic is that there is evidence that the particles on the order of 2 to 4 mm are the ones that are most harmful to the ecosystem since they are being ingested by the creatures at the bottom of the food chain.



Density estimates

While two trawls made 130 miles apart are inconclusive, it is interesting to look at the density of plastic measured by the trawls. The mass was measured after oven drying the samples for 2 hours and separating the organic matter. The area covered was measured by the distance traveled by the ship during the time the trawl was active as measured by the GPS positions at the start and end of the trawl. The effect of current was not known, but would not likely be more than ¼ knot or 10% of the ships speed of 2.5 knots. The two trawls produced an average density of 9.8kg/km^2 which is close to 92% more than recorded by Charles Moore in 2001.

Table 2

				Results of Screen Sizing of Plastic Debris												
									Mass of dry plastic captured by:							
Date	time in	Start	End		flow		Area		1/4" mesh	1/8 net	screen	plankton n		% capture	Total wet	Ratio
	time out	Location	Location	Speed	meter	Distance	swept	density	X>5.64	5.54>X>4.0	4.00>X>1.34	1.34>X>0.5	total	by 1/4 mesh	weight	total wet
				knots	m	m	m^2	g/m^2	g	g	g	g	g			dry plastic
08/22/09						(naut. m)		(kg/km^2)	44	1.4			47.4	93%	939.4	(20/1)
	6:27	38° 42.46'N	38° 48.?'N	2.5	NA	10384	6334	0.00748		0.1	1.4	0.5				
	8:20	140° 47.09'W	140° 46.09'W			(5.61)		(7.48)	44	1.5	1.4	0.5				
08/21/09	6:20	37° 29.035'N	37° 33.801'N	2.5	7579	9020	5502.2	0.0121	63.7	1.5	1	0.3	66.8	95%	208.6	3.1/1
	8:26	140° 53.966'W	140° 55.226'W			(4.87)		(12.1)			0.3					
									63.7	1.5	1.3	0.3				
						mean	kg/km2	9.81								

Conclusions

The experiments with passive systems demonstrated that it is possible to concentrate plastic particles found in the gyre with passive systems. The data from the active manta trawls made on the same location on the same day as the passive trawls in not yet available for comparison, however, it seems clear from visual evidence, that passive systems can be designed that greatly reduce the amount of bycatch of living organisms compared to the results of an actively towed trawl.

The question remains if such as system can be used to harvest plastic on a large scale, and what would be the cost? The systems tested collected plastic without human input or outside source of energy. Questions that were not answered include: 1)How long can a passive system be left in the water before it becomes fowled with marine life or the net clogged with fine particles and no longer functions? 2)If a system is used that depends on specific conditions such as opposing currents or swells of a particular height, what percentage of the time will it actually be effective? 3) What is the cost of producing the device and (4) what is the cost of servicing it?

A Speculation

For the sake of beginning the discussion and perhaps putting the size of the problem in perspective, let us use the average collection rate for the beach on the two days discussed or 4.7g/hr. Let us further suppose that the *beach* could be scaled up to have an opening of 7.3m (24 feet) and mass produced economically. If the servicing vessel could haul then clean and redeploy 50 units in a day and if the units can remain out for one week without being tended. Then the yield at the end of a week would be 270kg (595lb). If this could be converted to diesel fuel at 70% efficiency, it would yield roughly 209 lt (55 gal) of fuel or $166 in value. In other words the economic value gained would not significantly defray the cost of operations. But let's continue. If a tender ship is operated at $10,000 per week, and 100 ships could bring in enough material to support a recycling plant on a barge, the weekly cost would be $1,000,000 plus the cost of operating the plant, and overhead so let's say $2,000,000. The value of the fuel produced would be $16,600 at $3.00/gal. Based on the figure of 5kg/sq km as the density of plastic in the gyre and if the concentrated portion of the gyre is roughly 800km by 1500km, there are 6.1 million kilograms of material near the surface. Our 100 ships collecting 26,900kg/week would take 227 weeks or 4.4 years to pick it up. Assuming operations could only take place during the calmer weather of summer this would be more like 16 years. The cost would be $455 million. As the plastic diminishes, the cost of picking up the remainder would obviously increase. The area used in the calculation is a fraction of the total area containing plastic and it can be assumed that the plastic would continue to collect in the area for many years even if the source is cut off today. Clearly the first priority is not to add any more plastic to the ocean. If it is to be cleaned up, it will be extremely costly.