MARINE PLASTIC POLLUTION: VARYING IMPACTS ON MARINE WILDLIFE IN OREGON'S COASTAL ZONE

by

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Plastics have varying impacts on wildlife in Oregon's coastal zone. Production increases and wider distribution of plastics in the North Pacific now have identifiable effects on individual marine mammals and seabirds. Local quantities of marine plastics are difficult to estimate when combined with general oceanic circulation, which increases the influx of plastics from distant ocean sources. Fishing activities, trawl net and monofilament line loss, coupled with entanglement in crab pot lines, are the primary sources of potentially harmful plastics in Oregon's waters. Derelict nets and monofilament line entangle, drown or disable marine wildlife, and plastic

fragments are ingested by marine birds. Today, quantitative data of impacts on wildlife populations in Oregon are limited, but qualitative ones on pinnipeds, cetaceans, seabirds, and shorebirds have been observed by scientists.

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To the sun, the wind, the sea, and the stars.

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CHAPTER I

INTRODUCTION

Plastics have been produced for over a hundred years and have been found in the marine ecosystem for several decades. Plastics impact wildlife by altering habitats, entangling animals, being ingested as food, and otherwise impeding the ecosystem functioning.

Technological advances within the fishing industry have led to the increased production, diversity, and use of plastics. Consequently, increased amounts of plastics are polluting coastal zones, largely as a result of intentional and unintentional disposal. These plastics have not gone unnoticed, for they have clearly affected wildlife and marine habitats.

Fishing gear is the major source of plastics that are harmful to Oregon's marine wildlife and threaten the coastal habitat. Gear is often lost, wears out, or breaks into pieces; storms displace some collection devices (e.g., crab pots); and operator errors lead to broken nets and ropes. Net fragments are also intentionally discarded overboard; some foreign fleets cut nets to avoid citation, or they set more nets than can be retrieved before the end of a specified fishing season (National Oceanic & Atmospheric Administration [NOAA], 1988). Lost or discarded fishing gear either floats or sinks in the water column. Very little is known about the rates of change in buoyancy and vertical migration of fishing gear. Theoretically nets could sink from the weight of catch, slowly rotting and being eaten, and eventually rise back up in the water column to repeat the cycle. Lost gear, however, moves with the ocean's surface currents or the mean bottom flow (Coe, 1986).

Plastics are now having an observable effect on some species in the coastal zone. As marine plastic concentrations increase, so do interactions between discarded plastics and wildlife. It is this interaction that I have chosen to study. I have investigated the sources, quantities, and types of plastics entering the marine environment of Oregon's coast, and have tried to determine the types of plastics that have had the most visible effects in Oregon.

This thesis is a review of the plastics found in the North Pacific, with particular attention to specific ecological impacts on life there. The object is to gauge the scope and magnitude of the abundance of plastics in Oregon's coastal zone and the effects on living resources.

Even though much is known about plastics in other geographic regions, even the North Pacific, little information is available regarding the specific sources, quantities, and impacts of plastics in Oregon's coastal zone. This study will identify the major types and sources of plastics in Oregon's coastal zone that are responsible for the most distinctive impacts on marine life.

What are the sources of plastics in Oregon's coastal zone? How much plastic is discarded in Oregon waters? What impact do marine plastics have on Oregon's wildlife? Which types of plastics are most dangerous to marine life? Does oceanic circulation play a major role in the plastic pollution problem off Oregon's coast? Are fisheries-related wastes from Oregon the most detrimental plastic wastes in the coastal zone? What are the local sources of the plastic debris, and to what extent do these local sources modify the living resources?

It is impossible to gauge all sources of plastics and their respective quantities in Oregon. However, rough estimates give a fairly accurate general picture of the sources, quantities, distribution of plastics and of their impact on the coastal zone. The numbers are derived from brief surveys, snapshots taken in a highly dynamic system. In particular, the data on the Oregon coastal zone are limited because of the following factors:

1. The surveys of plastic distribution are inaccurate because they are based on visual observations of a wide variety and size of objects during variable climatic conditions (winds, sun's glare, and height of seas).

2. The data on known impacts to wildlife are merely conservative estimates because they are limited to the organisms that are observed or stranded after entanglement, ingestion, or snagging. An unknown percentage goes unobserved and unreported.

3. The majority of the data pertains to buoyant plastics because of their relative ease of observation. An unknown percentage sinks to the ocean floor or throughout the water column, but still takes its toll on unknown and unobserved individuals.

4. Much of the data reviewed was bound into regional categories not specific to Oregon's coast. It was then necessary to look at the data in a regional setting, rather than on a state level.

5. Estimates of ship-borne wastes are limited by outdated criteria for establishing the average percent of plastics that passengers discard per day.

6. Since December 31, 1988, strong educational programs and legal enforcement of The Act to Prevent Pollution from Ships (1989) have potentially changed

disposal practices by both individual passengers and vessel operators.

7. Beach surveys are not an accurate and proportional measurement of the wastes in the marine ecosystem because buoyant plastics are predominantly deposited ashore.

8. We do not know how much waste really originates from each source, or how much plastic is presently in the ocean due to previous disposal practices.

In addition, this study was limited in its extent by other factors:

1. Chemical pollution from the leaching of plastics at sea was not investigated.

2. Only species of the continental shelf were studied because the highest concentration of living resources and the highest amount of human use and exploitation occur in this area.

3. Only sources specific to Oregon were reviewed in depth, even though activities off the coasts of Washington, California, British Columbia, and other foreign nations have an impact on Oregon's wildlife.

4. Possible positive outcomes, such as plastics creating a new substrate in the water column for encrusting organisms, were not reviewed in depth.

Methodology

The study area is limited to the coastal zone of Oregon (42° N latitude to 46° 15' N latitude). This zone includes all estuarine waters, near-shore coastal waters and waters over the continental shelf. In Oregon, the continental shelf ranges from 15 to 76 km wide down to a depth of 200 meters (Peterson, Kulm, & Gray, 1986). The reason for focusing on the coastal waters inland and over the continental shelf is that the highest concentration and widest diversity of the living marine resources reside in this zone.

In this study, "plastic" is defined as all petrochemical compounds that modern society refers to as plastics and which comprise clothing material (polyester and nylon), building materials (fiberglass, etc.), fishing nets (polyethylene, polypropylene, polyamide), and a myriad of containers and styrofoam products.

Harmful impacts are defined as those that alter, impede, harass, or terminate the pre-existing normal function of a particular individual or species of organism. These include entanglement, encirclement, snagging, ingestion, and concealment (creating an impermeable obstacle) by plastics that have been introduced in the marine ecosystem. Derelict gear refers to fishing wastes, primarily nets and traps, that are lost or discarded in the water and continue to catch either target or non-target species.

I reviewed all relevant literature and information related to plastics in the global oceans, with particular reference to the North Pacific and coastal waters off Oregon's coast. Information on the thesis topic was obtained through a review of the available literature on marine debris, including government data and reports from various local, state, and federal agencies, commissions, and task forces, and in discussions with field biologists, state, and federal agency personnel.

CHAPTER II

NATURE AND SOURCES OF PLASTICS IN THE MARINE ENVIRONMENT

History

John Wesley Hyatt first synthesized plastic in the late 1860s. Since their original discovery, new inventions and a huge production boom have led to the widespread distribution of plastics. Today, plastic has become one of the most widely used materials on a volume basis (Society of the Plastics Industry [SPI], 1988) and has become a symbol of our modern "throwaway society."

In the 1930s and 1940s today's major thermoplastics--polyvinyl chloride, low density polyethylene, polystyrene, and polymethyl methacrylate--were developed. The demand during World War II for substitutes for products such as natural rubber and silk increased the use of plastics. At this time in the United States, intensive research and development led to large scale production of synthetic rubbers, which fostered the initial research on the chemistry of polymer formation. The first decade after

World War II brought the development of high density polyethylene and polypropylene, with an enormous growth in applications. Large-scale production greatly reduced the cost of manufacture, and the new wonder plastics began competing with traditional materials such as wood, paper, metal, glass, cotton, hemp, and leather (SPI, 1988).

Plastic resins are made by linking small groups of molecules (monomers) into long chains called polymers. These plastics are produced by the resin production industry, which is primarily comprised of large chemical companies that convert industrial organic chemicals into plastic resins. The resins are then shipped to thousands of plants nationwide and extruded, injected, blow-molded, and formed into thousands of end products. Chemical additives are used during plastic processing so that the finished product will have specific qualities--for example, rigidity or flexibility, color or lack of it, strength or weakness. Each year has brought new and stronger plastics with more varied applications for this expanding industry.

Types of Plastics in the Marine Ecosystem

Polyethylene, polystyrene, polyvinyl chloride, and polypropylene are the most common types of plastics found in the marine ecosystem (Pruter, 1987). Polyethylene is commonly used in the manufacture of jugs, bottles, buckets, construction sheeting, packaging film, wire and cable coverings, and shipping pallets. Polystyrene is used in foamboard, disposable cups, and small strands of packaging materials. Polystyrene and polyurethane foams are used for flotation devices in the fishing industry or in marinas and ports. Polyamide (nylon), polyester, polyethylene, and polypropylene are the primary materials used in fishing gear (Pruter, 1987).

Qualities of Plastic

The desirable qualities of plastics--lightweight strength, durability, ease of production and handling, low cost, and versatility--have made them prime materials for large scale production. Because of its adaptable qualities, plastics had invaded the fishing industry by the late 1950s; and by the late 1960s all natural materials, such as hemp and flax, had been replaced by the new plastics in nets, ropes, traps, and lines (Uchida, 1985). The very qualities that have made plastics so desirable to industry have made them potentially undesirable to the marine environment.

Buoyancy

The density of plastics affects the position they will assume in the water column once they have been introduced into the marine environment. Plastics are composed of synthetic compounds with differing specific gravities. There is no data on the proportion of discarded plastic gear that will sink or float (Sibley & Strickland, 1989), and so we cannot accurately estimate what amount of lost gear floats at the surface or sinks further down in the water column.

The buoyancy of nets varies with the type of plastics used in construction. Plastic is usually positively or neutrally buoyant. Thus, it tends to stay at the surface. Heavy pieces such as acrylics, cellulosics, substituted polymers, and vinyl polymers are found on the bottom of the sea floor. Medium density pieces, possibly polystyrenes, and styrene copolymers are thought to stay suspended in the water column in the colder, denser layers (Morris, 1980b).

The two categories of nets, surface nets and subsurface trawls (Uchida, 1985), respond differently in water, based on the difference in the plastic used in their fabric. Trawl webbing is predominantly polyethylene, which is less expensive and positively buoyant (Coe, 1986); synthetic ropes are made with polypropylene and will float; while gill nets are made with polyamide, which is negatively buoyant. The trawl nets are weighted and deployed in the bottom and midwater of the ocean, while the gill nets have floats and are deployed at the surface. The trawl nets will rise up in the water while they are weighted at the bottom, and the gill nets will sink like a curtain with floats holding at the surface. Netting caught on the bottom, such as trawl webbing, tends to stay vertical in the water if the floats are still attached (Wallace, 1985). Polyethylene is also easier to handle on deck and it floats off the bottom when snagged, thus reducing further snagging in attempts to free it. Broken mesh pieces of trawl webbing will float for almost all trawls. The small pieces may not be big enough to accumulate a large catch and will never sink, thus limiting removal to beach deposition (Coe, 1986).

Longevity of Plastic and Removal Mechanisms

Plastics are very durable both in the sea and on land. Coleman and Wehle (1983) indicated that plastic on beaches may last from 5 to 50 years. Sunken nets may last more than 50 years (Wallace, 1985), and nets on beaches have a rapid rate of return back into the marine ecosystem (Merrel, 1984). These plastics are highly resistant to natural decay in the marine environment, but may physically fragment into smaller and smaller pieces. Most result from weathering and microbial action (Pruter, 1987).

Plastics are removed from marine waters chiefly through deposition on beaches. Very little plastics are left on rocky or pebbled beaches. Most are deposited on sandy beaches (Wallace, 1985). On the Oregon coast, plastic deposition increases after winter storms (Merrel, 1980; Neilson, 1985). Once plastics are deposited, they are buried or transported further inland by the winds, overgrown by vegetation, gnawed on by rats, decayed somewhat by microbial action, or are resuspended in the ocean waters (Merrel, 1980).

Environmental degradation of plastics is minor. Photo-oxidation, ultraviolet chemical breakdown, erosion by sand, molecular breakdown through heating and aging, and fragmentation by wave action (Wallace, 1985) are all insignificant. For instance, Dixon and Dixon (1981) found that older plastic containers have an existence of approximately four years before they break down and fragment from embrittlement. The more flexible plastics, such as twine and netting, are much less vulnerable to embrittlement and fragmentation. Another minor removal mechanism is from sinking in the water column, which only transfers the plastics from the surface layer to the benthic layer. In regard to fishing nets, this occurs when the nets release their floats and sink, are snagged on the sea floor, or are filled with too many fish.

Sources of Marine Plastics

Overview

There are two sources of plastic pollution in the marine ecosystem. The first involves land-based sources, including beach users, plastic manufacturing and transportation, plastic processing facilities, solid waste management facilities, combined sewer outflows, and (in Oregon) oyster farming. The second type of plastic pollution is oceanic and encompasses the fishing industry, commercial shipping, recreational boating, offshore drilling and mining, military activities, research vessels, and passenger ships. Some estimates have been made for the quantities of plastics that these vessels discard, but none for the quantity of land-based plastics entering the ocean. It is believed that the major sources are from commercial vessels--fishing and merchant shipping, and that these sources contribute the most potentially harmful plastics to the ocean.

Plastics enter the marine ecosystem via a myriad of sources. Coe (1986) and Laist (1987) identified the types of plastic entering the marine ecosystem as: (a) raw plastic spherules or beads; (b) fishing gear, including webbing, twine, ropes, floats, traps, and pots; (c) packaging from strapping bands, padding, cases, bags, bottles, and other containers; and (d) convenience items such as utensils, six-pack holders, cups, etc. Of these categories, both fishing gear and packaging material are primarily related to ocean vessels. Merrel (1980) believes that the vast majority of plastic pollution originates from the fishing industry near fishing grounds. The fishery-related plastics enter the water through the loss of net material due to wear, tear, snags on the bottom, and intentional disposal by fishermen (Wallace, 1985). General shipping is another major source of plastics in the marine ecosystem. The plastics associated with shipping are: plastic baggies, lines, rope, twine, packing bands, six-pack holders, and plastic pellets for packing cargo (Wallace, 1985). Land-based sources come from the plastic resin industry either losing or accidentally discharging these pellets in processing or transportation. Morris (1980a) suggests that these pellets are already so ubiquitous in the oceans, with such a high density worldwide, that their source is now unimportant. Another land-based source derives from beach picnickers, but Merrel (1984) concluded that the contribution by picnickers to beach litter was minimal relative to the amount of litter from ocean deposition.

Land-Based Sources

Some land-based sources of plastic marine pollution are known and traceable. The primary source is from the industry involved in the processing, manufacturing, and transportation of plastic. The plastic resin industry produces the raw plastic pellets that are the basis for processing all plastic items. These resin pellets are made at large petrochemical processing plants that synthesize these small cylinders, nibs, or beads into sizes ranging from 0.12 mm to 6 mm in diameter. They are then transported in bulk by train car loads, trucks, or ships in 50-100 pound bags to processing plants. At the processing plants they are melted and fabricated into consumer and industrial products (NOAA, 1988). The likely sources of these raw plastic pellets' infiltration into the marine ecosystem are through accidental spillage in ports; overflow into municipally operated treatment plants; movement through streams, rivers, and storm drains after spillage in processing plants; or loss in transport (Gregory, 1978). Cases have also been reported of deliberate dumping of thousands of tons of raw plastics into the ocean (NOAA, 1988). Even though there have been no studies done, it has been accepted that the primary sources of these pellets are the result of transportation of pellets to manufacturing sites from production sites, through accidental loss from trucks, ships, and trains.

Resin Pellet Production

Nationwide there are over 10,000 plastic processors, with 11,653 plants in the molding and forming industry (Wirka, 1988). In 1982, the Census of Manufacturers showed that there were 264 resin producers with 441 plants in the United States. These resin producers produced 8,197 million pounds of plastic resin in 1962 and 55,751 million pounds in 1987. Between 1962 and 1987 there has been a 7.9% average annual increase in production; between 1982 and 1987, an 8.7% average annual increase; and between 1986 and 1987, there was a 9.6% annual increase in production (SPI, 1988). Projections for plastic production maintain these growth patterns. In 1985, the United States produced 48 billion pounds of plastic resins, and by the year 2000 it is anticipated that these plastics will exceed 76 billion pounds (Wirka, 1988). Pellets, once processed, can be lost or discarded through many avenues. A certain amount may be discarded right at the plant, and some may be lost during domestic and foreign trade as a result of outfalls during loading and unloading. Resin pellets are also used on vessels as packing material insulation or as "ball bearings" to facilitate the moving of cargo boxes and other heavy objects (Pruter, 1987). This use on vessels increases the chance of disposal at sea. Colton, Knapp, and Burns (1974) point out that the overall misuse of plastics will continue to increase for some time, even if control measures are implemented immediately.

Wastewater Dischargers

Plastics could also enter the wastewater stream from manufacturing and processing operations. The Environmental Protection Agency prohibits the deliberate discharge of solid materials into waters, thus eliminating the possibility of major amounts of plastic entering the oceans this way. Combined sewer outflows (CSO) and publicly owned treatment works (POTW, or sewage treatment plants) may discharge plastics into the waters, although documentation is minimal. Colton et al. (1974) found small polyethylene cylinders in the effluent of plastic manufacturing plants. This possibly occurs when storm waters exceed local plant capacity. Some POTWs are only designed to handle dry weather flow, and sewage bypasses the system in wet months or during plant breakdowns. In the United States there are over 15,000 POTWs, with 2,307 in coastal counties, discharging effluent into the rivers and streams. Only 570 of these 2,307 discharge treated effluent into the nearby coastal waters (OTA, 1987).

Ocean-Based Sources

Fishing Industry: North Pacific

There have been major changes in the fishing industry in the last 40 years. The greatest change came from shifting away from natural fibers and to long lasting plastic fibers in net construction and fishing gear. This shift began in the 1940s and by the beginning of the 1970s was virtually complete for most of the major fishing nations. Of course, this transfer to plastic fishing gear has brought with it new problems for the living resources in the marine ecosystem. Plastic fishing gear is now being lost, dumped, or broken into pieces in the oceans. As the intensity of fishing has increased in the North Pacific, so has the amount of lost or discarded fishing gear.

The modern fishing industry has developed because of three technological revolutions: mechanization, echo sounding, and development of plastic fibers (Uchida, 1985). Nylon was the first synthetic fiber to be developed that possessed excellent characteristics for constructing the ideal fish net. Thus more intensive fishing began, using more durable, nondegradable, and potentially harmful gear to the living resources. Today there are many differences in gear used and fishing methods employed; fishermen have adapted and modified their gear according to cultural differences and based on their knowledge of fish habitats and behavior patterns (Uchida, 1985).

Specifically, four kinds of fishing gear are most commonly involved in the entanglement of marine wildlife: (a) trawl webbing, usually constructed with polyethylene, has its origins in the groundfish fishery; (b) monofilament gill nets are primarily used by high seas drift net fisheries for salmon, squid, and tuna/billfish, and by coastal surface and demersal gill net fisheries (e.g., in the Columbia River); (c) monofilament fish lines, which originate in the commercial hook and line fishery, are also used for recreational hook and line use (Coe, 1986); (d) synthetic ropes of floating polypropylene are another source that is related to merchant shipping, though it is more often related to commercial crabbing and fishing in coastal waters. These commercial fishing plastics are the primary source of plastic debris in Alaska's region (Merrel, 1985) and are believed to be the major burden to wildlife in Oregon's waters, too.

The varying types of compounds used in the production of fishing gear affect the way in which the material will respond in seawater. The extrusion of polyamide into monofilament line enabled the manufacture of a wide variety of monofilament and multifilament gill nets. Polyamide (nylon), polyester, polyethylene, and polypropylene are the principal plastics used because of their high tensile strength, resistance to rot, and relative invisibility (Coe, 1986).

Recreational Boating

Recreational boaters are a source of plastic pollution in marine waters. These boaters add some plastic by the litter of beverage containers and packaging material, but more importantly, from the disposal of monofilament line. This line causes specific impacts to marine wildlife.

Navy and Research Vessels

The United States Navy and National Oceanic and Atmospheric Administration vessels are responsible for a certain amount of plastics in the marine environment, although these wastes are usually crew related and have a relatively minimal impact on marine wildlife. The Navy has over 600 vessels worldwide carrying nearly 285,000 people. They generate and discharge over 4 tons of plastic into the ocean per day (NOAA, 1988). These vessels are not required by U.S. law to store their wastes, so direct discharge is considered acceptable. There are 226 U.S. Coast Guard and NOAA research vessels, most of which operate in domestic waters and carry approximately 9,000 personnel (NOAA, 1988).

Cruise Ships

Cruise ships may be another source of plastic waste in marine waters. These wastes are generally domestic garbage: containers, cups, utensils, bags, tampons, condoms, etc. Approximately 15 cruise ship companies operate out of 6 major and 32 smaller U.S. ports (NOAA, 1988). No cruise ships operate out of Oregon ports, and plastic inputs in Oregon's coastal waters are believed to be minimal.

CHAPTER III

QUANTITIES AND DISTRIBUTION OF PLASTIC IN THE MARINE ENVIRONMENT

Overview

There are a multitude of sources of plastics in the marine environment, with a wide variety both in the quantities of inputs and the process of distribution, once discarded. The overall ubiquity of plastics is demonstrated by their presence in the Southern ocean, on the remotest southern beaches (Gregory, 1978), distant arctic beaches (Wong, Green, & Cretney, 1974), and plastics have even been reported on an island just off Antarctica (Wallace, 1985). Today, plastics comprise over half of all human-made objects sighted at sea (Dahlberg & Day, 1985; Venrick et al., 1973; Morris, 1980a), without including the extensive distribution of minute plastic pellets and fragments which are too difficult to sight from ships. The abundance of these plastics ranges from 0.15 objects km^{-2} in the Subarctic waters of the North Pacific (Dahlberg &

Day, 1985), to 1,200-1,400 objects km^{-2} in the Mediterranean (Morris, 1980a).

Physical and Climatic Factors

Local factors influence the types and amounts of plastics that end up in Oregon's coastal zone, which debris will be deposited ashore, and which will remain in the water column. Current patterns, climate, tides, upwelling, and winds all affect how plastics are transported into the coastal zone. Tides and currents tend to concentrate plastics, just as they would concentrate food items in the sea surface (Norris, 1986).

North Pacific Currents

The currents in the North Pacific are highly complex and variable, with shifting directions and varying speeds. However, some generalizations can be made about permanent ocean currents in the North Pacific. Currents are produced by the Earth's rotation, wind stress, tides, waves, and upwelling. These currents are the major transporter of plastics. The geostrophic flow (earth-turned currents) flow below the upper, wind-mixed layer. The wind and wave drift transports the upper layers through the direct action of the wind stress on the sea surface. The wind drift (Ekman flow) and the wave drift (Stokes drift) may result in appreciable speeds in the upper 50 meters of the ocean during strong winds. Long waves, or planetary waves, result from interactions with the bottom topography or from strong velocity shear (Reed & Schumacher, 1985). The tidal currents, or currents associated with the rise and fall of the tide, have little influence on the ocean currents unless they occur at depths of 100 meters or less. The tidal currents are not important in the open ocean, but in relatively shallow waters they do have some play over the movement of material in the near-shore waters (Reed & Schumacher, 1985).

The Subarctic Current, part of the westwind (North Pacific) drift and 500-1,000 km wide, carries water eastward across the Pacific and typically splits off the Coast of Vancouver Island (see Figure 1 by Reed & Schumacher, 1985) to form the northward-moving Alaska Current and the southward-moving California Current (Baily & Parmenter, 1985). The Subarctic Current is strongest in the winter, when the average flow is about 5 cm/s, but strong winter winds may augment the flow in the upper mixed layer. In general, the California Current is broad, slow, and shallow. It flows offshore as a diffuse band about 500 km wide with an average speed of 10 cm/s (Oceanographic

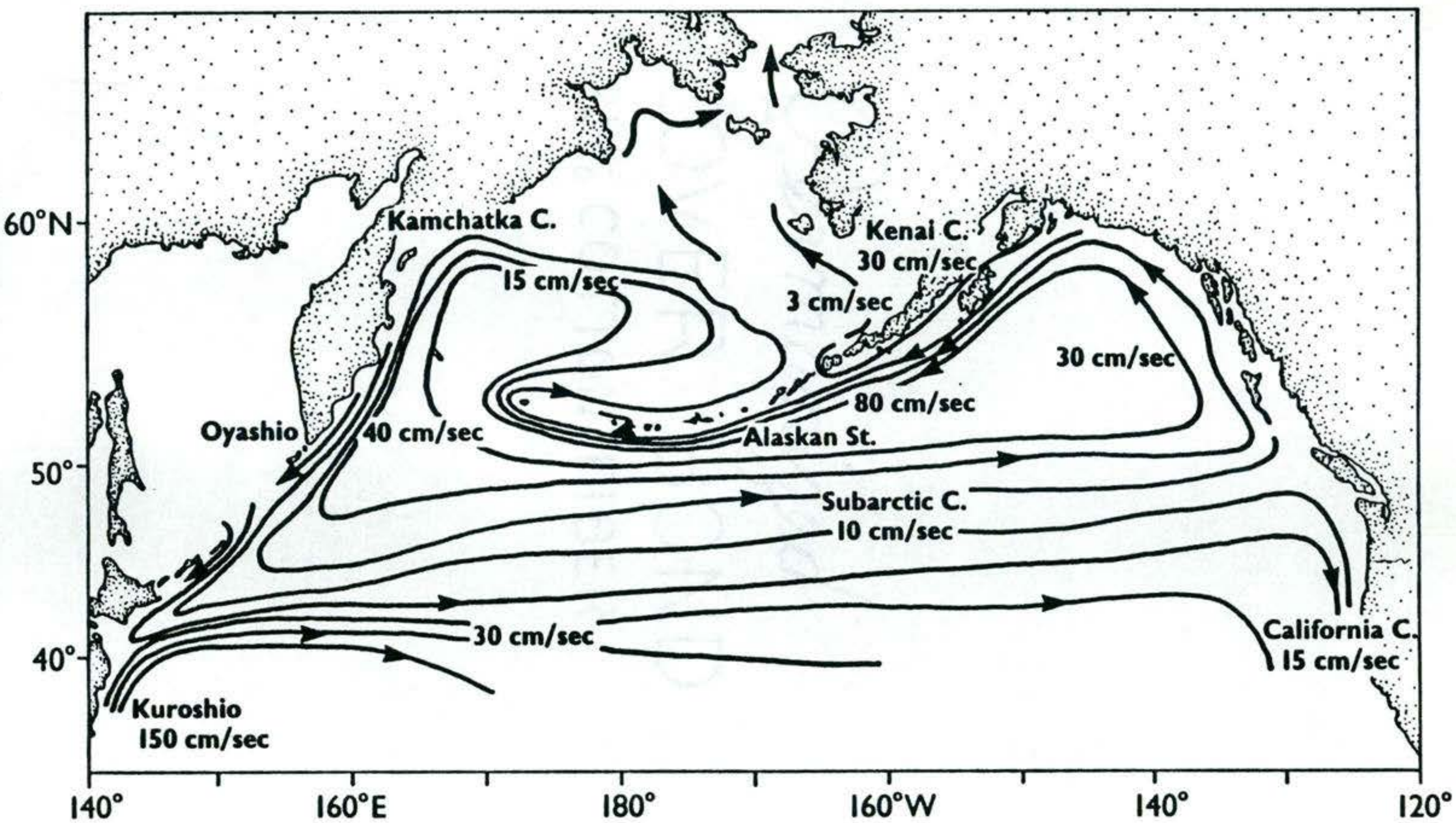

FIGURE 1. Estimates of the Climatological Mean Surface Circulation in the Subarctic Pacific

Institute of Washington [OIWA], 1977; Baily & Parmenter, 1985). It reaches its maximum strength in the summer when the surface winds are consistently from the northwest.

Distribution and Quantities

The overall distribution of plastics is patchy and uneven in response to uneven inputs, changing wind patterns, and varying local currents. However, certain patterns of distribution are discernible: marine litter tends to concentrate along coastlines because 80% of merchant marine activity is within 40 km of land (National Academy of Sciences [NAS], 1975); major fisheries are concentrated over the continental shelves; recreational boating is generally in near-shore waters; and the rivers and estuaries discharge directly into coastal waters.

Once in the marine ecosystem, the distribution of buoyant plastics follows general patterns of current distribution and is heavily influenced by winds and currents (Wallace, 1985). Wong et al. (1974) found a wide range of debris close to land, within 500 nautical miles from shore. Morris (1980b) found only the lightest, most buoyant plastics in the open ocean far from their original sources. Due to lack of research, accurate estimates are unavailable regarding midcolumn and benthic distribution and quantities.

The first estimates of oceanic plastic quantities were made by the National Academy of Sciences (1975), but it is now believed by researchers in the field that the original projections were unrealistically low. Coe (1986) made a conservative estimate in 1984 that there were 1 million vessels in the seas, which yielded 43.5 million pounds of plastic waste and 24.7 million pounds of lost fishing gear. Horseman (1982) estimated that at least 450,000 plastic containers are dumped each day from the world's fleet of shipping vessels. He also estimated that 23,000 metric tons of packaging from the fishing industry are discarded yearly. Add to this the annual disposal of 135,000 metric tons of plastic fishing gear and the severity of the problem is obvious. The National Academy of Sciences (1975) only estimated crews to be a source of 340,000 tons of unspecified debris other than fishing gear. NAS (1975) estimated the amount of fishing gear discarded to be 1,350 metric tons per year; yet, to Merrel (1980), these estimates were incorrect and more on the order of 135,000 metric tons of discarded fishing gear annually, including 1,664 tons in the Gulf of Alaska alone. Merrel (1984) also estimated fishing vessels to contribute 1,361 tons in the Bering Sea, with 145,000 discarded net fragments. Other important sources of marine plastic pollution originate from military and research vessels, recreational boats, drilling and mining platforms, and catastrophes that are estimated to add 280,000 tons of plastic annually (Pruter, 1987).

Surface Distribution

These plastics have varying concentrations in the North Pacific, ranging from 0.15 objects km^{-2} in the subarctic (39-56° N latitude), to 3.15 objects km^{-2} in the subtropical (21-39° N latitude) from Alaska to Hawaii, and (27-42° N latitude) from Hawaii to Japan (Dahlberg & Day, 1985). These estimates are only for floating debris (see Table 1) that is easily identified. Debris that is lost due to sinking in the water column is not included in these sighting surveys. Other problems with these surveys include the distance of objects from the boat, varying sea conditions, sun's glare, color of objects, and differing buoyancy.

Dahlberg and Day (1985) found that 86% of all floating debris in the North Pacific was plastic. Many plastic objects were heavily encrusted with fouling organisms and heavily faded, suggesting that they had been adrift for a long time. Dahlberg and Ignell (1986) found 87% of all debris sighted in the North Pacific was plastic or styrofoam. They found the highest densities at 41-42° N latitude, with decreasing densities in the eastern

TABLE 1. Abundance of Small and Large Plastics in North Pacific and Bering Sea, 1972-1985

Size	Location	Mean Density (objects x km^{-2})	References
Large	Subtropical North Pacific	2.24	Venrick et al., 1973
Large	Subtropical North Pacific	3.15	Dahlberg & Day, 1985
Large	Subtropical North Pacific	1.83 ± 2.41	Day & Shaw, 1987
Large	Subarctic North Pacific	0.15	Dahlberg & Day, 1985
Large	Subarctic North Pacific	0.94 ± 1.22	Day & Shaw, 1987
Large	Subarctic North Pacific	0.23 ± 0.19	Day & Shaw, 1987
Small	Subtropical North Pacific	96,100 ± 780,000	Day & Shaw, 1987
Small	Subarctic North Pacific	3,370 ± 2,380	Day & Shaw, 1987
Small	Gulf of Alaska	132	Shaw, 1977
Small	Bering Sea	68	Shaw, 1977
Small	Bering Sea	80 ± 190	Day & Shaw, 1987

Note. From "Patterns in the Abundance of Pelagic Plastic and Tar in the North Pacific Ocean, 1976-1985" by Robert H. Day and David G. Shaw, 1987, Marine Pollution Bulletin, 18(6B), p. 313.

longitudes. They sighted an average of 3.54 nets per 1,000 nautical miles. Between 30-41° N latitude there is believed to be a surface convergence wherein the layers of the Ekman transport cause accumulations of floating material from waters both north and south. Dahlberg and Day (1985) found that the two heaviest concentrations in the North Pacific were between 50-52° N latitude and 31-39° N latitude in small zones of downwelling. The second largest concentration was in a zone of surface convergence caused by converging Ekman transports between 28-42° N latitude (Dahlberg & Day, 1985). See Table 2.

Distribution of Plastic Pellets and Fragments

Plastic pellets (raw polyethylene and polypropylene) are distributed worldwide: in the Gulf of Alaska (Day et al., 1985), the Sargasso Sea (Carpenter & Smith, 1972), the Cape Basin in the South Atlantic (Bourne & Imber, 1982), in New Zealand waters and elsewhere in the world's ocean (Gregory, 1978). There are higher densities in large ocean gyres such as the Gulf of Alaska and the Sargasso Sea (Day et al., 1985; Carpenter & Smith, 1972). The concentration of these pellets has been shown to be up to 21 items per 2.5 cm^3 in sediments downstream of factory outfalls (Wallace, 1985). Surface concentrations ranging from 101-250 grams km^{-2} were found several hundred miles

TABLE 2. Reports on Visual Observations of Floating Plastics in the North Pacific

Region	Abundance	References
Central North Pacific	2.2 plastic objects km^{-2}	Venrick et al., 1973
North Pacific: Alaska Hawaii, then to Japan	0.15 objects km^{-2} (subarctic) & 3.15 km^{-2} (subtropical)	Dahlberg & Day, 1985
North Pacific	14 net fragments per 19,498 km transit	Jones & Ferrero, 1985
Western North Pacific	2.5-5 net fragments 10,000 km^2	Lenarz, 1985
Central North Pacific	1.835 gill nets in 1,000 km transit	Laist, 1987
West Pacific & Bering Sea	0.2-1.7 net fragments in 1,000 km transit	Fowler, 1987

offshore (Wallace, 1985), and Wong et al. (1974) found up to 34,000 pellets km^{-2} in the North Pacific, with a distinct peak in concentration in the eastern Pacific, believed to be related to the predominantly western winds.

Surface tows have estimated plastic fragment concentrations in the oceans, as seen in Table 3 (Wong et al., 1974; Shaw, 1977; Shaw & Mapes, 1979). In a recent survey in the North Pacific, Day et al. (1986) found five basic types of small plastic objects that reside in the surface of the water column. Plastic fragments--chips, sheet fragments, and other pieces from larger objects--comprised the majority (91.7%) of all plastic. Monofilament line and fragments--single strands of plastic--comprised 2.9% of the surface debris. Styrofoam fragments amounted to less than 1% of the tow, followed by 0.5% from plastic pellets and polypropylene fragments (mooring lines and fishing nets). They found the mean density to be 48,500 pieces km^{-2}. The highest density was observed at 40° N latitude, with 165,000-202,700 pieces km^{-2}, followed by high concentrations between 39-42° N latitude, with 57,700 pieces km^{-2}. Day et al. (1986) believes the input of raw plastic pellets into the oceans has been greatly reduced in the last 10-15 years, while the major component of small (less than 2.5 cm^3) floating plastics is from plastic fragments of broken, brittle, items other than raw plastics.

TABLE 3. Reports on Surface Net Tows for Plastics in the North Pacific

Region	Abundance	References
North Pacific	Plastics present in 64% of tows 35° N latitude absent at 125° W longitude	Wong et al., 1974
N.E. Central Pacific along 158° W longitude	0-400 g/km^{-2}	Shaw & Mapes, 1979

The "raw" plastics are in the highest concentration near the major production areas, major cities, and ports, but are still found on remote beaches, too (Gregory, 1978). These plastics have a general resistance to degradation and are extremely durable in the marine environment. The accumulation and concentration of plastic litter of this type on beaches is widespread (Cundell, 1973; Wong et al., 1974); it washes up and accumulates on the beaches at the drift line and often becomes covered by drifting sands.

Net Fisheries in the North Pacific

Many major net fisheries in the North Pacific utilize vast amounts of plastic net gear. These nets are from high seas fisheries in international waters to more near-shore coastal fisheries. Gill nets, purse seines, trawl nets, set nets, haul seines, tangle nets, and lift nets are some of the many types of nets used. In 1985 the known production of these nets and assumed usage was 170,000 km of gill net, 2,000 km of purse seine, 5,500 km of trawl nets, and 8,900 km of miscellaneous net gear (Uchida, 1985). These fantastically large amounts of fish gear in use present definite hazards when in use or when intentionally and unintentionally discarded.

Gill nets, the most abundant nets, create a wall of plastic netting that either forms a noose around heads and bodies or entangles legs and spines of marine animals. These are versatile nets that can be utilized on the surface, in the midwater, or on the bottom. In the 1950s, the gill nets were introduced in the North Pacific to replace linen nets.

Major sources of drift gill nets come from the foreign fisheries in the North Pacific. The Japanese use drift gill nets for their salmon fishery and now have offshoots of this high seas fishery for billfish and squid drift netting. The billfish fishery began full-scale operation in 1972. After the oil shock of 1973, many Japanese fishermen switched to drift gill nets because of the relatively smaller amounts of fuel consumption. In 1978, the Japanese developed a squid fishery to target Red Squid, Ommastrephes bartrami, to be fished after they closed their salmon season (Uchida, 1985). Today, Taiwan and the Republic of Korea also have a squid gill net fishery. Taiwan's gill net fishing industry developed rapidly from catching 8,475 metric tons in 1970 to 53,856 metric tons in 1983. The total number of gill net vessels increased from 524 in 1970 to 1,284 in 1982 (Chen, 1985). This fishing takes over 90% of its catch from between 35-40° N latitude and 140-170° W longitude (Gong, 1985).

The relevance of these foreign, high seas, drift gill net fisheries is that their lost commercial gear potentially affects living resources in Oregon's coastal zone. The gill nets in the salmon and squid fisheries are a single strand of monofilament net that ranges from 9 miles long in the Japanese salmon fishery to 14-20 miles long in the squid gill net fisheries in Japan, Taiwan, and Korea. A total of 20,500 miles or more of drifting gill net is employed every night (Sibley & Strickland, 1989). The range of operation of these fisheries extends over 4,000 miles east to west from the Soviet Union to Alaska and further south. These nets are frequently lost at sea, causing "ghost fishing" (nets lost, discarded, or cut loose), and will target all species that can become entangled in the nooses of the netting. These nets will continue to take species and alter ecosystems as they move into different depths of the water column, and they may disable ships (Recht, 1988b; Wallace, 1985). The configuration of these lost and discarded nets will determine their potential impact on the ecosystem (Coe, 1986).

Trawl Nets

In coastal waters, trawl nets are probably the most likely plastic fishing gear to harm wildlife because of their extensive local use. These trawl nets are produced with either polyamide, which tends to sink, or polyethylene, which will float. They are bag-shaped nets towed through waters to catch fish near the bottom or in the midwater column. The mesh sizes vary from 1 1/4 inches for small shrimp to 6 inches wide for cod and pollock. These sizes entangle many species other than the initial target species. These nets are primarily lost by snagging on the ocean bottom or overloading with fish catch. In both cases, the nets are either cut or broken loose from the fishing boats (NOAA, 1988). In Alaska, trawl netting has frequently washed ashore (Fowler, 1987; Merrel & Johnson, 1989; Merrel, 1980, 1984), and other areas where trawling occurs, such as the Oregon coast, are presumed to lose trawl netting.

Trawling effort has greatly increased in the past 30 years on the Pacific coast (see Table 4). In waters off Oregon, Washington, and British Columbia, Japan and the USSR began a groundfish trawl fishery years ago. In recent years off the Pacific coast, the overall trend in foreign fishing effort was downward, about one third the effort in 1983 compared to the 1975 season. The fishing effort by the joint fisheries has increased markedly in the past years (Fredin, 1985), which has offset the decreasing

TABLE 4. Average Annual Trawl Effort in 1000-Hour Units for the Bering Sea, Aleutian Islands, and West Coast of the United States

Date	Trawl Effort
1956-60	234
1961-65	537
1966-70	641
1971-75	782
1976-80	764
1981-83	794

Note. From "Fishing Effort by Net Fisheries in the North Pacific Ocean and Bering Sea Since 1950s" by R. A. Fredin, in Proceedings of the Workshop on the Fate and Impact of Marine Debris, Honolulu, Hawaii, November 27-29, 1984 (pp. 218-252, NOAA Technical Memorandum NOAA-TM-NMFS-SWFS-54), edited by R. S. Shomura and H. O. Yoshida, 1985, Washington, DC: U.S. Department of Commerce.

foreign effort. Between 1956 and 1971 the domestic groundfish effort was stable, but has more than doubled since (Fredin, 1985). The total trawling effort for foreign, domestic, and joint venture fisheries in the trawl groundfish fishery from British Columbia to California has more than tripled since 1956 (Fredin, 1985).

Net Loss

The world's fishing fleet has dramatically increased in the last 2 decades. Since this increase, there has been a substantial increase in the amount of fishing-related debris (Uchida, 1985; Wehle & Coleman, 1985), but now the new plastic gear is more buoyant, longer lived, and nearly invisible in the water, as compared to the old, natural materials. These qualities have led to an overall increase in the mortality of marine organisms. These derelict nets are often broken into large and small fragments and may fish indefinitely. These nets can entangle crustaceans, fish, mollusks, marine mammals, sea birds, and sea turtles.

Nets create drag in the water, and strong currents may often deform them, pull them downward, or flatten them if they are not anchored properly, and then they may drift away (Uchida, 1985). In the North Pacific, gill net losses are thought to be the greatest, followed by trawl nets and then other net fisheries.

Derelict nets have different residence times in the surface and midwater depths of the sea. A derelict gill net at the sea surface has a residence time of 2-10 years (Wallace, 1985). It is estimated that the Japanese salmon fishery alone has an annual average loss of 296 km of gill netting (Merrel, 1984). Discarding these nets is illegal by Japanese law, but the law is not enforced (Sibley & Strickland, 1989). A certain portion is inadvertently or intentionally discarded. Trawl webbing is used predominantly over the continental shelf. The bottom trawls are highly susceptible to loss (Uchida, 1985), and the rate of loss of these nets is expressed in units of time trawling rather than length of the net. Once these trawl nets are lost, they are considered to rise up in the water column whether they are attached on the sea floor or not. In Alaska, a total of 65 nets or portions of nets were estimated to have been lost in 1983, with a total of 2,114 vessel months of trawling effort. The loss rate per vessel month was calculated at 0.03% (Sibley & Strickland, 1989). We can apply this loss rate to the trawling effort off Oregon to estimate the amount of trawl nets lost directly in Oregon's waters.

Monofilament Line

Monofilament line is another fishing-related plastic that has critical effects on marine organisms. It has its origins in both the commercial hook and line industry and in the uses of recreational fishermen. An unknown quantity of monofilament line is lost per year, but it is believed to be many thousands of miles. This plastic line easily tangles on fishing reels and is frequently cut off and discarded, or fishing gear snags on the ocean bottom and then is cut off for removal. Monofilament line is usually negatively buoyant, so it is thought to sink and tangle benthic organisms.

Benthic Data

There is little information about the amount of plastics on the sea floor, and there has been no systematic attempt to characterize and quantify either the types of debris that sink to the sea floor or the distribution and magnitude of their biological impacts. Answers to many of these questions are currently unavailable because of a lack of appropriate data. However, Jewett (1976) and Feder, Jewett, and Hilsinger (1978) do describe debris found in bottom trawls off the Gulf of Alaska and the eastern Bering Sea. Jewett (1976) found 57% of objects in debris trawls to be plastic. Feder et al. (1978) found plastic in 43 of his 106 trawls. Conservative estimates show 43 items per 4.2 km^2, or 10 items per km^2 in the Bering Sea, and in the Gulf of Alaska, 7.8 items per km^2 (Sibley & Strickland, 1989). High (1985) used a submersible to observe organisms captured in underwater "ghost nets" that were snagged on the bottom. The plastic nets that were found in benthic debris were hypothesized originally to be snagged on the bottom and more likely to be found there.

Vessel Traffic

The concentration of ocean-going vessels correlates with the amount of vessel-related plastic wastes discarded in coastal waters. The merchant marine traffic may discard cargo-associated wastes such as plastic strapping bands and plastic sheeting, or crew-related wastes including plastic containers, utensils, styrofoam cups, etc., all of which have an influence on the marine environment. The major portion of plastic pollutants, cargo-associated wastes, have been shown to be the most detrimental to marine organisms. Plastic strapping bands, which are typically polypropylene or nylon, are used in shipping to bind items or boxes together (NOAA, 1988). Plastic sheeting, which is typically polypropylene, is used aboard ships to cover items during transport (NOAA, 1988).

Foreign flag vessels carry most of the U.S. ocean-borne, commercial trade cargo. Between 1977 and 1987 these vessels carried a high of 96.3% of commercial trade cargo in 1980, and a low of 94.2 % of all commercial trade cargo in 1983 (Center for Marine Conservation [CMC], 1989). For instance, Panama, Liberia, Greece, Japan, and Cyprus account for 55% of vessels calling at U.S. ports. The foreign vessels present the problem of having different disposal practices for plastics, and little enforcement of laws governing these practices.

Since 1975, container ships have become a significant mode for moving cargo around the seas. These container ships decrease the quantity of cargo-generated wastes in the ocean because the container is not open except during loading and unloading (NOAA, 1988). In 1976 about 10% of the world's shipping fleet was containerized, and by 1986 one third of the fleet was containerized (NOAA, 1988). The average crew size has decreased, too, from 40 persons down to an average of 25 today, thus reducing crew-related wastes.

Beach Surveys

Beach litter can be an indicator of types of oceanic debris, density of debris, and an index of possible changes in oceanic density and spatial variability of debris

(Merrel, 1984). Plastic debris is primarily removed by continual tidal action and winds, or storms that blow over the coast. We make certain assumptions about the litter that is found: that plastic beach debris is in some way related to proportions of oceanic debris, for instance. However, the spatial distribution may be highly variable, as in the case of fishing nets being highly clumped over the continental shelf (Merrel, 1984).

Merrel (1980) found detectable concentrations of plastics reaching beaches far away from population centers. Merrel (1980, 1984, 1985) conducted beach surveys of debris found on remote Alaskan beaches. He found high concentrations of plastics, 98% of which was fishing related (see Table 5). These beach surveys may not give an accurate, proportionate profile of all debris in the marine environment, but they do provide some information for inference. For instance, we can generalize that the variety and quantity of plastics found in the marine environment, whether on shore or in the water, have dramatically increased (Horseman, 1982; Pruter, 1987; Bean, 1987). Of this plastic debris, Coleman and Wehle (1983) found that most comes from oceanic sources.

TABLE 5. Reports on Plastic Debris on Beaches on the Pacific Coast of North America

Region	Abundance	References
Arctic beaches of Southern Beaufort Sea	Plastics associated with seismic exploration most common	Wong et al., 1976
Beaches of N.W. Hawaiian Islands	7.4 pieces of net & line km^{-1}	Henderson, 1988
Beaches of Amchitka Island, Alaska	1972: 122 kg km^{-1} 1973: 345 kg km^{-1} 1982: 255 kg km^{-1}	Merrel, 1984
Beaches of Amchitka Island & S.E. Alaska	Mainly commercial fish gear: trawl web decreasing, floats increasing	Merrel, 1985

Alaskan Beaches

To date, studies in Alaska have generated the most accurate data regarding accumulation of plastics on beaches. Alaskan coastal waters have similar activities to Oregon waters: trawling, crabbing, recreational fishing, and debris transported from the subarctic current. Merrel (1980) found hundreds of plastic items on remote Alaskan beaches, but, of the thousands of items found, only 24 types that occurred more than 5 times. Of these, 11 articles comprised 98% of the total weight of commercial fishing gear plastics, of which 80% was dominated by trawl webbing. Over a two-year study, Merrel (1980) documented a 250% increase in the total number of items (from 2,221 to 5,367), with a 284% increase by weight. The exponential increase of the 24 most common items found in his first survey represented an annual growth of 59%. Another pattern Merrel (1980) recorded was the increase of plastic accumulation during storms. Merrel (1985) also noted that most litter found in beach surveys came from foreign fisheries. Of this litter, trawl webbing constituted the bulk by weight, and Japanese gill net floats were the most numerous item. Between 1974 and 1982, an overall decrease in the amount of plastic litter deriving from trawl webbing and gill net floats was attributed to the decrease in trawlers and gill netters off Alaska.

CHAPTER IV

IMPACTS OF PLASTICS ON WILDLIFE

Overview

Plastics affect marine organisms through many avenues. Entanglement and ingestion are common among marine mammals, birds, fish, crustaceans, sea turtles, and benthic invertebrates. Birds are frequently entangled in fishing line and nets, or they may swallow bags and plastic fragments (Kenyon & Kridler, 1969; Day et al., 1985). Seals and sea lions can become girdled with strapping bands and rope, or entangled in net fragments (Balazs, 1985; Calkins, 1985; Fowler, 1985; Scordino & Fisher, 1983). Whales are also commonly entangled in nets and in synthetic rope, which is used as crab pot lines (Mate, 1985; O'Hara et al., 1986). Fish may swallow plastic objects or become entangled in net fragments and monofilament line (Balazs, 1985; Bourne, 1985; Carpenter, Anderson, Harvey, Miklas, & Peck, 1972; Degange & Newby, 1980). Crustaceans become entangled in discarded fishing line (Fowler & Merrel, 1986) and in other types of plastic. For years after their loss, gill nets have been observed to continue catching fish, crabs, and diving sea birds (High, 1985). Other benthic invertebrates, particularly in estuaries, may become obstructed by plastics that settle over them (M. Graybill, personal communication, December 13, 1989).

Marine wildlife interact with plastics in varying ways, depending upon the individual organism's perception of plastic. They may accidentally interact with plastics when they do not perceive the danger of such objects, which can lead to entanglement in line or netting. In other instances they fail to discriminate between plastic and organic matter. In some cases, they may be incapable of such discrimination. Some species of birds may ingest plastics that are the same color and size as their ordinary diet, or they may use plastic line in building their nests. Other times marine organisms, particularly pinnipeds, will deliberately interact with plastics because of a natural curiosity to seek out and investigate an object (Wallace, 1985). Other detrimental interactions may create an additional substrate for attachment by marine organisms, or facilitate parasitic exploitation--e.g., tube worms' use of resin pellets to build their tubes (Wallace, 1985).

Entanglement of marine life has many possible negative effects. The animal may be killed outright, as in the case of drowning. In other instances, entanglement may diminish animals' ability to swim and feed, and ingested items may suffocate, cause internal damage and blockage, or starve the animal by creating a false feeling of satiation (O'Hara et al., 1986). Entanglement of marine mammals probably occurs incidentally through their playing with fishing gear, or trying to remove previously captured prey from nets (Fowler, 1988; Stewart & Yochem, 1987). Ingestion is most apparent in seabirds: they can either mistake plastic for their natural prey species (Day & Shaw, 1987; Fry, Fefer, & Sileo, 1987) or succumb to secondary intake by eating fish that contain plastics.

The population effects of plastics are poorly known, but physical effects on individuals are apparent. Normally species' populations fluctuate in response to climatic factors or other environmental variables, but understanding of the effects plastic entanglement and ingestion have on populations is minimal. A growing body of evidence suggests that plastics are affecting population levels (Fowler, 1987), especially ecologically sensitive, threatened species like the Hawaiian Monk Seal or the Northern Fur Seal.

Impact to Marine Mammals

Marine mammals have been subject to the most obvious impacts from plastics. When caught in plastics, or washed ashore when entangled, much notice is taken by the public, and reporting is more likely. Several activities can lead to entanglement for these mammals: (a) encountering lines and nets meant for other species; (b) playing with nets, lines, and loops; (c) or hauling-out on piles of plastic netting. Wallace (1985) defines entanglement as: "the unintentional harassment, injury, and mortality of organisms through physical means by objects or foreign material in the marine environment." These plastics have unknown mortality rates, but will potentially strangle, starve, drown, or cause serious cuts and infections to animals. Most of the observations of effects have been done on land, while a certain unknown and potentially high proportion of mammals die before being observed when returning to land (Scordino & Fisher, 1983).

Entanglement by plastics is mainly mechanically destructive, since it may drown individuals, decrease the individuals' ability to catch food or avoid predation, or inflict wounds from abrasive cutting (Laist, 1987). Of plastic debris, net webbing is the most commonly encountered entangling debris for pinnipeds (67%), followed by 19% from plastic strapping bands, 3% from cords used in net construction, 1% from ropes, and 5% from strings (Scordino & Fisher, 1983). Drowning occurs primarily in large fragments of nets that are 10 pounds or more. Medium fragments account for exhaustion, depletion, and starvation from increased net drag, infection from open wounds, and skin necrosis from encirclement (Scordino & Fisher, 1983). Other examples may include ingestion; the Pygmy Sperm whale, Rough-Toothed dolphin, Curvier's Beaked whale, and Minke whale have all been observed ingesting plastics (Wallace, 1985). In Oregon, Mate (1985) found a stranded Sperm whale who contained approximately one liter of tightly packed plastic trawl net in its stomach.

Pinnipeds

As observed by Feldkamp (1985), when pinnipeds are caught in a plastic line or net, they will thrash violently about, and within a few minutes they may become so entangled as to limit mobility. In these cases the pinniped is believed to drown immediately; otherwise, necrosis and open wounds may occur within a few hours. Entanglement will usually occur around the neck, and less frequently around the head and shoulders (Scordino & Fisher, 1983).

Stewart and Yochem (1988) found a difference between entanglement rates of seals and sea lions (see Table 6), which they concluded was due to differing modes of propulsion and a differing ability to break netting. Merrel (1980) found that sea lions became entangled primarily in the first 2-3 years of life. Scordino and Fisher (1983) found that, since 1967, the North Pacific Fur Seal has averaged a known rate of entanglement at 0.40%. In 1967 it was calculated at 0.15%, and 0.72% in 1975. Of these entanglements, Stewart and Yochem (1988) confirmed that in California waters 27% were due to assorted marine debris and 73% to interactions with commercial gill net fisheries. Fowler (1987) found that trawl net fragments were the most common entangling gear in Alaska (see Table 7).

Impact to Birds

Seabirds and shorebirds have been noted worldwide to have interactions with marine plastics (Baltz & Morejohn, 1976; Bayer & Olsen, 1988; Day, 1980; Day et al., 1986; Dean, 1985; Fry et al., 1987). Interactions with marine plastics involve both entanglement in active or lost fishing gear (net pieces and monofilament string) and ingestion of plastic pellets and fragments. Shorebird entanglement is mainly responsible for drowning, while

TABLE 6. Types of Plastics Entangling Pinnipeds at San Nicolas and San Miguel Islands, 1984-1986

Species	Monofilament Line	Gill Net	Trawl Net Fragments	Packing Bands	Other Debris[a]	Total
California Sea Lion	10	36	2	17	4	69
Northern Elephant Seal	12	5	2	13	4	36
Harbor Seal	0	0	0	1	2	3
Northern Fur Seal	0	0	1	0	1	2

Note. From "Entanglement of Pinnipeds in Synthetic Debris and Fishing Nets and Line Fragments at San Nicolas and San Miguel Islands, California, 1978-1986" by Brent S. Stewart and Pamela K. Yochem, 1987, Marine Pollution Bulletin, 18(6B), p. 338.

[a]Includes rubber bands, polyfilament rope and line, and other items.

TABLE 7. Types of Entangling Plastics Found on Northern Fur Seals on St. Paul Island, Alaska, 1981-85

Type of Plastic	Number of Seals 1981	1982	1983	1984	1985	Total
Trawl Net Fragment	68	62	79	50	53	312
Gill Net Fragment	0	3	2	4	2	11
Cord from Net Repair	3	4	2	2	5	16
Packing Band	20	26	18	20	8	92
String	5	3	2	4	0	14
Rope or Line	1	2	2	5	7	17
Plastic Ring	1	0	1	1	0	3
Plastic Gasket	0	0	2	0	0	2
Monofilament Line	0	1	0	0	0	1
Six Pack Holder	0	1	0	0	0	1
Packing Web	0	0	1	0	0	1
Miscellaneous	2	0	0	0	1	3
Total	100	102	109	86	76	473

Note. From "Marine Debris and Northern Fur Seals: A Case Study" by Charles W. Fowler, 1987, Marine Pollution Bulletin, 18(6B), p. 328.

plastic ingestion may lead to intestinal blockage, internal ulcerations, decreased appetite, and toxic accumulation from leaching plasticizers. Of these impacts, entanglement causes a high degree of mortality, while ingestion is less obtrusive but appears more frequently.

Ingestion

Ingestion of plastics has been reported in over 50 species of seabirds (Fry et al., 1987) and has been correlated with feeding habits (Day et al., 1985; Fry et al., 1987). The first documented case involved the Laysan Albatross (Kenyon & Kridler, 1969). Since then, various reports have sprung up implicating a few families of birds as the primary targets of plastic ingestion. Procellariiformes (albatrosses, shearwaters, fulmars, and petrels) and Charadiiformes (phalaropes, auklets, and puffins) are most frequently found with plastic in their upper intestinal tracts (van Franecker, 1985; Day et al., 1985). Fry et al. (1987) report that the Laysan Albatross has the highest known incidence of ingested plastics in the gastrointestinal tract (see Table 8). The chicks suffer from high proportions of proventricular impactions and ulcerative lesions, and thus have a high mortality rate. In other species, such as shearwaters, up to 60% contained plastic, yet intestinal impaction is not considered a significant hazard because of the birds' regurgitative abilities (Fry et al., 1987).

TABLE 8. Incidence of Plastic Ingestion by Layson Albatross Chicks, Midway Island, Northwestern Hawaiian Islands

Date	Number of Chicks with Plastic (Number with/Total Number)	%
August 1982	3/4	75.0
April 1983	16/17	94.1
May 1983	5/5	100
July 1983	45/50	90.0
Total	69/76	90.8

Note. From "Ingestion of Plastic Debris by Laysan Albatrosses and Wedge-Tailed Shearwaters in the Hawaiian Islands" by Michael Fry, Stewart Fefer, and Louis Sileo, 1987, Marine Pollution Bulletin, 18(6B), p. 340.

The most commonly collected plastic particles by seabirds in the marine environment are polyethylene, polystyrene, and polypropylene of 1-5 mm in diameter. These plastics are either raw pellets from manufacturing or small weathered fragments from embrittled plastic (Carpenter et al., 1972; Colton et al., 1974; van Franecker, 1985; Day et al., 1985). For example, Baltz and Morejohn (1976) found rigid and flexible plastics, including polyethylene and styrofoam, in the stomachs of nine species of shorebirds. Fry et al. (1987) found large fragments of plastic (2-10 cm) in albatrosses and pelicans, while small fragments were found in plankton-feeding birds such as shearwaters, petrels, prions, phalaropes, and auklets.

Plastics have varying risks to birds. When plastic is consumed in high quantities, it can cause physical obstruction, and chicks in particular are more at risk because they have a lower frequency of regurgitative casting (Fry et al., 1987). Yet, with adults, the risks associated with ingestion are not necessarily present due to the birds' regurgitative ability.

Some argue that plastics have potential toxic effects to birds. Carpenter et al. (1972) found PCB concentrations of 5 parts per million on the surface film of plastic spherules. They believed the presence of toxics in or on plastic to pose a potential and serious hazard to birds. The chemical toxicity of plastic polymers, plasticizers, and chemical additives is considered minimal, although many pigments are toxic (containing heavy metals and organochlorine) and may serve as a vehicle for adsorption. For example, according to EPA rankings in 1986, five of the six chemicals whose waste is most hazardous come from plastic: propylene, phenol, ethylene, polystyrene, and benzene. Other additives in plastic which are known carcinogens and mutagens are cadmium compounds, carbon tetrachloride, lead compounds, vinyl chloride, chromium oxide, diazomethane, and styrene. Fry et al. (1987) believed these potential toxic effects to be minimal when contrasted with potential impacts of intestinal blockage.

Entanglement

Entanglement of birds is usually limited to drowning in netting (both active and inactive) or monofilament line. In particular, diving birds comprise 60-80% of seabirds caught in netting (Wallace, 1985). The most important variables for determining entanglement are: (a) distance from shore, (b) time of year, (c) proximity of breeding colonies, (d) types of fishing in area, and (e) mesh size of nets used. Once diving birds are entangled, they will probably die. Seabirds are attracted to fish that have been previously caught in netting; hence, both active and derelict nets will entangle birds. Jones and Ferrero (1985) reported that one derelict, 15-km gill net, found off Alaska in 1981, contained 350 dead seabirds. Other isolated incidents have been reported involving shorebirds' construction of nests with plastic line and netting that can cause future entanglement.

CHAPTER V

OREGON: A CASE STUDY

Oregon's Coastal Zone

Coastal Geography

The Oregon coastline is characterized by a series of sandy beaches (64%), interspersed with rocky headlands (36%), and 172 stacks, islands, and reefs (Oregon Coastal Conservation and Development Commission [OCCDC], 1974). The coastline runs in a north/south direction and thus is subjected to the full impact of breaking waves and storms that move across the Pacific Ocean. In the winter the waves are severe, and there is turbulent mixing and moving of sediment far out on the continental shelf.

The offshore geography of Oregon is characterized by a relatively narrow continental shelf that is 15 km wide off Cape Blanco and widest off central Oregon, extending out to 76 km. Large submarine canyons are absent off Oregon's coast, with only one major canyon west of the Columbia River cutting the continental shelf. The sediment transport into Oregon waters comes from the many rivers, with the largest source from the Columbia. This coastal basin contains over 40 rivers and prominent streams that drain the areas west of the coast range.

Oregon Currents

The currents over Oregon's continental shelf change seasonally. Flow is generally southward in the spring and summer in conjunction with coastal upwelling, but the northward flow of the Davidson Current predominantly exists in the winter. This current is a local current off the Oregon coast that occurs in the winter and runs counter to the California Current (see Figure 2 by Parmenter & Baily, 1985). It flows northward, originating in northern California and terminating at the Straits of Juan de Fuca, attaining speeds of 25-45 cm/s and has a minimum width of 90 km (OIWA, 1977). This current develops off the coast of Oregon and Washington in September and becomes well established by January, then diminishes in spring and disappears by May. The Davidson Current flows over the continental shelf at all depths in the winter and is pushed further down in the water column in combination with the deep northward-flowing California undercurrent, over the continental slope, where it is slowed down considerably in the summer (see Figure 3 by Parmenter & Baily, 1985). These changes are probably a result of local wind stress;

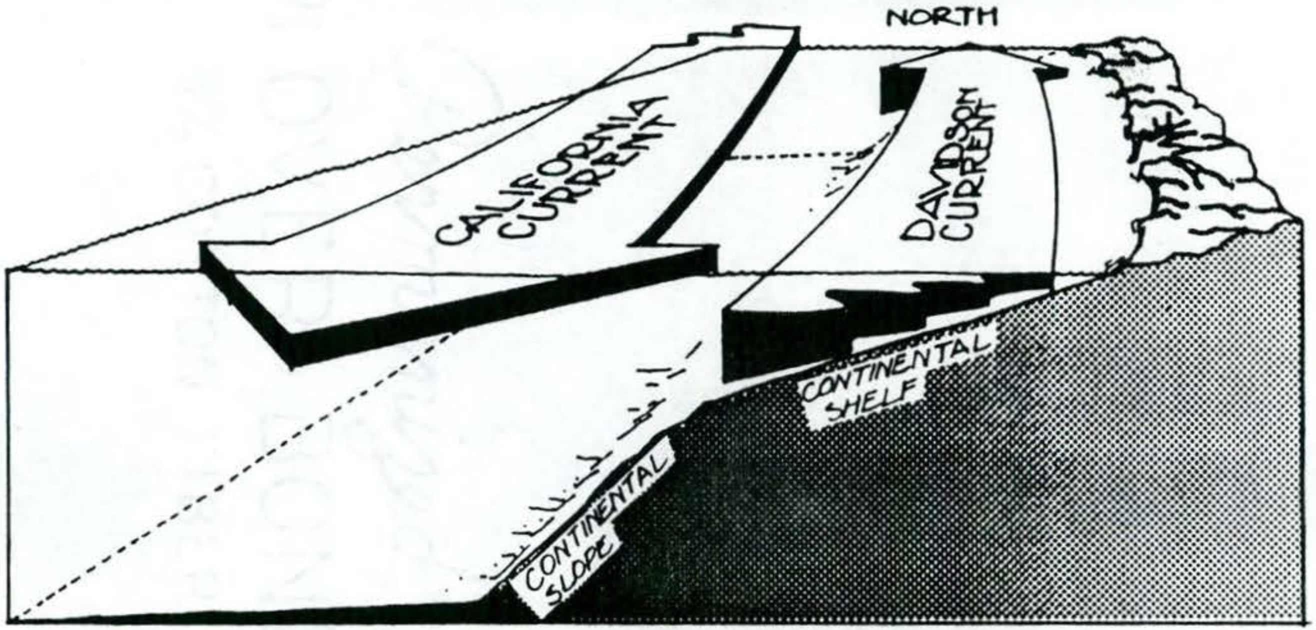

FIGURE 2. Winter Circulation off Oregon

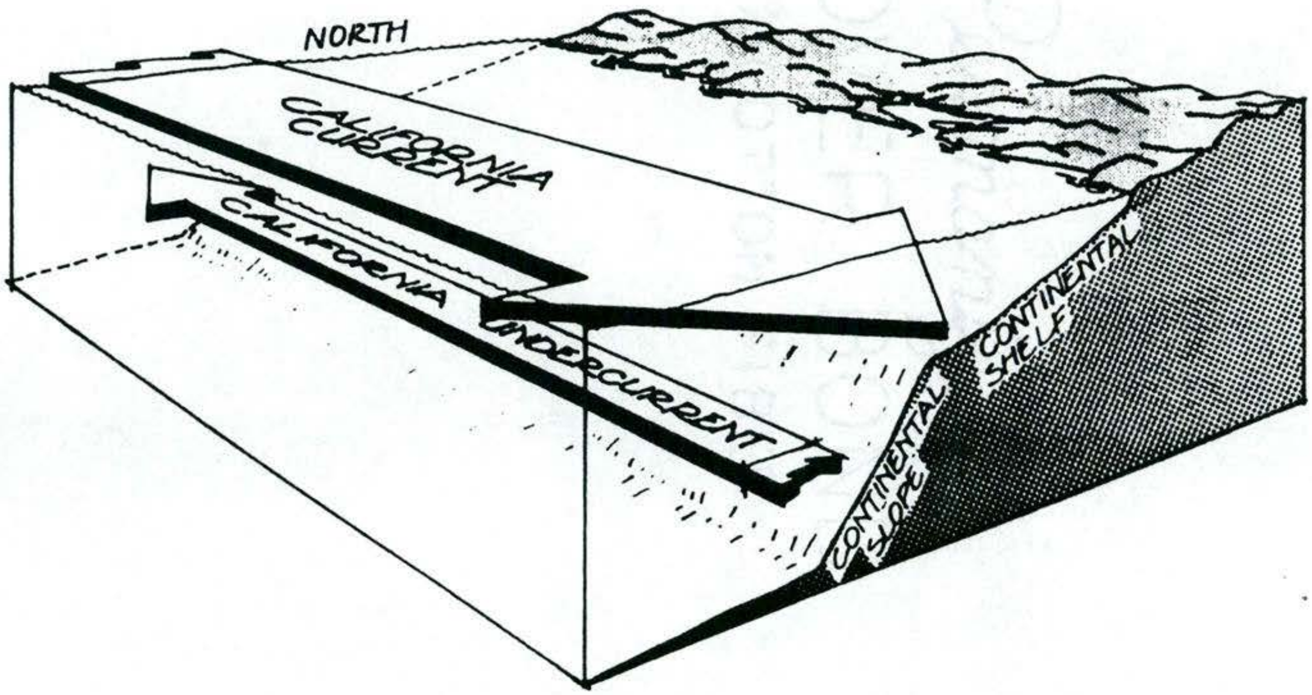

FIGURE 3. Summer Circulation off Oregon

however, large-scale winds deriving from pressure gradients along the shore also contribute to the variable currents (Reed & Schumacher, 1985). Estimates of seasonal variation in the many surface currents are as follows: (a) the Subarctic Current, 40-50° N latitude, moves east in the summer at a minimum flow of 5 cm/s, and east in the winter at a maximum flow of 20 cm/s; (b) the California current off Oregon moves southward in the summer at a minimum flow of 20 cm/s; and (c) the Davidson Current moves northward in the winter at a maximum flow of 20 cm/s (Reed & Schumacher, 1985).

These currents are an important factor for transporting plastics from distant waters into Oregon's coastal zone. An object that enters the ocean off northern Japan should arrive off the west coast about 2 years later. If the object sits high above the water, as some plastic objects do (e.g., containers, floats, styrofoam chunks), it might arrive off the coast of Oregon even faster. When plastics do enter the near-shore waters of Oregon, many factors can influence their fate. Waters that normally move along shore may be transported toward the shore with a storm. Off Oregon, plastic materials are driven onshore with the strong winds that probably exceed 30 cm/s, which is greater than the along-shore current velocity.

Wind and Atmospheric Factors

The prevailing weather system occurring off the Oregon coast determines the direction of the winds. In summer, the Oregon coast experiences primarily westerly and northwesterly winds. This is because of the North Pacific High pressure system, which moves northward in the summer bringing winds circulating in a clockwise direction, while the Aleutian Low contracts northward. In the winter, the Aleutian Low moves down over the Oregon coast, and the winds rotate counterclockwise, forcing prevailing southerly and southeasterly winds. These winds are stronger in the winter, frequently reaching 22-29 m/s (see Figure 4 by Oregon State University, 1971), bringing more intense winter storms (OIWA, 1977; Baily & Parmenter, 1985).

Coastal Upwelling

Upwelling from the bottom occurs near shore in the late summer months in response to the northerly winds that drive waters offshore by Ekman transport and then bring deep water to the surface. Strong northwest winds in the spring and summer produce surface currents that divert water to the right of the wind direction as a result of the Coriolis force (effect of earth's rotation). The surface layer transports a thin, 20-40 meter-deep flow of water

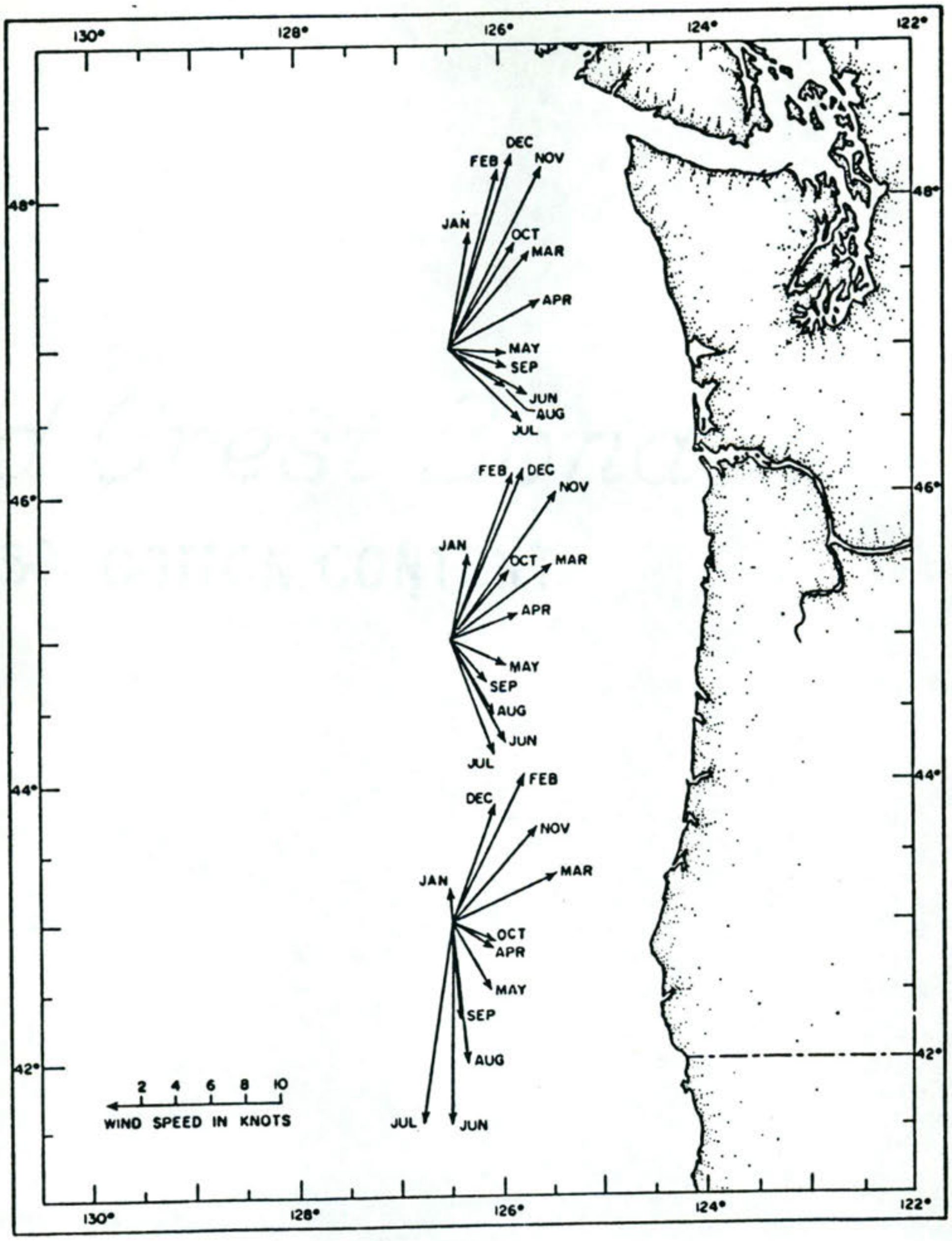

FIGURE 4. Wind Direction and Velocity

outward, while bringing up the cold bottom waters on the coastline, and is restricted to 10-30 km from shore. A coastal jet forms in the summer--a fast-moving, narrow, surface current flowing windward adjacent to the upwelled waters. Coastal upwelling may contribute to the transport of buoyant plastics offshore in the summer but may also deposit benthic plastics onshore from the influx of bottom waters. Likewise, in the winter, the strong southerly winds initiate downwelling, where the surface layer of the ocean piles up on the beach, and then sinks down to move back offshore (Baily & Parmenter, 1985). Downwelling may be one cause for additional accumulation of positively buoyant plastics in the winter.

Oregon Resin Production

In Oregon, there are no producers of raw plastic feedstock. There are almost 250 firms producing $850 million in plastic product shipments, most of which goes to outside states and nations (Society of the Plastics Industry of Oregon [SPIO], 1988). In Oregon, the principal place for manufacture of these plastics is Portland, but there are plastic firms in a total of 17 counties. Between 1982 and 1987, 53 new plastic firms opened up in Oregon, indicating a growing industry. These firms have been supplied with plastic resins from out-of-state suppliers

(SPIO, 1988). This lack of resin producers in Oregon limits the source of raw pellets getting to the oceans to their transportation and use at local manufacturing plants, the transportation in ocean currents, and transfers at dockside.

Wastewater Dischargers

In early 1968, Oregon law required permits to discharge any wastes into public waters (OIWA, 1977). Now in Oregon's coastal counties there are 116 wastewater dischargers--66 municipal and 50 industrial (Office of Technology Assessment [OTA], 1987). The average discharge of these 116 plants is 7.1 million liters of effluent per day from each source, or a combined 823.6 million liters per day, with the heaviest inputs from the wood products industry (OIWA, 1977).

Net Fisheries

Trawling began on the Pacific coast in 1876 off California and soon spread to Oregon and Washington. Otter trawls were used regularly off the Oregon coast by the 1930s. Trolling for salmon in Oregon's waters began in the early 1930s. The troll fishermen were mainly fishing for anadromous fish that were caught with hook and line in marine waters. The trawl landings by Pacific coast fishermen increased from 9,000 metric tons between 1926-1940 to 54,000 metric tons in 1975. On the Pacific coast, Washington and California trawlers will fish off Oregon's coast, and Oregon fishermen will fish off these states' coasts also. By 1962, foreign fishing fleets had come to the coasts of Oregon and Washington to trawl. The Japanese were the first, and they fished for rockfish, but not heavily in Oregon's waters because there are relatively small amounts as compared to further north or south. In 1966, the Soviets came to fish for Pacific Hake off the Pacific coast (OIWA, 1977).

Monofilament nylon webbing was first used by a few fishermen in Oregon in 1958. By 1959 it was banned, but remained legal for native American Indians. In 1965, a multiple-strand, monofilament gill net was introduced and legalized in Washington. For Oregon, drift gill nets are the only commercial gear allowed on the Columbia River for salmon, and trolling is the method used in ocean waters. These drift nets are up to 457 meters in length, and set gill nets up to 91 meters, on the Columbia River (Uchida, 1985).

Oregon Fishing Statistics

In Oregon, 18 ports harbor boats and harvest fishery resources. Oregon law mandates commercial fishermen to sell their catch to a licensed fish or bait dealer, who must keep accurate records of the transaction; although the port of landing does not necessarily indicate the origin of the catch, we can only assume that the numbers are fairly representative of the quantities and amount of fish taken in Oregon waters. The Oregon landings include ocean, bay or inland-caught fish and shellfish. In 1987, there were 3,109 fishing boat permits: 181 shrimp permits, 2,626 troll permits, 103 scallop permits, and 370 gill net permits (Carter & Lukas, 1989). In 1985, these fishermen landed 99,603,185 lbs., in 1986 they landed 113,822,428 lbs., and in 1987, 138,633,519 lbs. of fish. In 1987, landings by weight and gear type in the Columbia River were: 34,720 lbs. by coastal gill net, 12,187 lbs. by coastal set net, 5,722,552 lbs. by Columbia River gill net, and 11,435 lbs. by smelt trawls (Carter & Lukas, 1989). Landings by pounds and gear in 1987 along the Oregon coast were: 44,976,514 lbs. for the groundfish trawl, 12,220,183 for the midwater trawl, 46,947,891 lbs. for the shrimp trawl, and 109,214 lbs. for the ocean gill net (Carter & Lukas, 1989).

Crabbing

Crabs are harvested in traps and pots in Oregon. These traps have a circular metal frame 36-48 inches in diameter with 3- to 4-inch steel wire mesh, and sometimes plastic mesh. They weigh between 75-160 lbs., and each pot is attached to a 50- to 60-fathom-long plastic rope with two buoys, spaced 5-10 fathoms apart at the surface, presenting an obstacle to marine mammals. These pots are set in 18- to 480-foot depths of water and are checked every 1-7 days. They will remain in the water throughout the season from December 1st to August 14th and will catch up to 60 crabs apiece per haul. In 1985, 75% of Oregon's commercial crab catch was landed within 3 miles of shore (O'Hara, Atkins, & Iudicello, 1986). Collection of the most recent data (see Table 9) from 1977 was concentrated in Oregon coastal areas, surveying 650 fishermen with 60,285 traps. There were an additional 344 fishermen on the Columbia River with 24,226 traps (O'Hara et al., 1986).

Crab traps contain little plastic in themselves, whereas the plastic crab line is the cause of a host of potential impacts to marine organisms. High (1985) estimated that hundreds of Dungeness crab pots are lost yearly from Alaska to California (see Table 10). Estimates show that up to 30,000 crab pots have been lost on the continental shelf in the Gulf of Alaska alone (High & Worlund, 1979). In Oregon, California, and Washington,

TABLE 9. Crab Catch in Pounds in Oregon for 1987

Species	Amount Caught
Box Crab	24
Bay Dungeness Crab	62,499
Dungeness Crab	5,928,370
Rock Crab	5,321
Tanner Crab	121

Note. From Pounds and Values of Commercially Caught Fish and Shellfish Landed in Oregon 1987 (p. 69) by Chris Carter and Gerry Lukas, 1989, Portland, Oregon: Oregon Department of Fish and Wildlife.

TABLE 10. Reported Claims in Oregon and Washington to Fishermen's Vessel and Gear Compensation Fund in 1985

Fishery	Number of Traps Lost	Number of Buoys	Amount of Rope (feet)
Black Cod	197	35	146,760
Sablefish	519	136	182,922
Dungeness	175	628	56,370
King Crab	63	243	79,854
Total	954	1,042	465,906

Note. From Plastics in the Ocean: More Than a Litter Problem (p. 12) by Center for Environmental Education, 1987, Washington, DC: Author.

escape panels are now required by law on Dungeness crab pots (Sibley & Strickland, 1989). High (1985) estimated that these lost crab pots may fish for up to 6 years before becoming sanded in.

Oyster Production

Oysters have been grown and harvested in Oregon for years. Recently these mariculture practices have changed, and oyster farming operations have begun using plastic lids in the production process. Once the oysters are harvested, the lids are discarded in the bays and estuaries. The number of these lids is growing rapidly, covering the tidal muds and covering the high tide line with a spotted line of plastic lids. The lids may cover up organisms, such as sand shrimp, that live in muds.

In Oregon, oysters are produced on state lands in the bays and estuaries. Pacific oysters, *Crassostrea gigas*, comprise 99.9% of the oysters harvested. Since 1976, production has grown steadily to 40,706 gallons in 1987. The production levels have grown from 20,768 gallons in 1976, to 33,730 gallons in 1981, to 40,706 gallons in 1987 (Oregon Department of Agriculture, 1988; Carter & Lukas, 1989). Oysters are grown in four bays in Oregon: Tillamook, Netarts, Yaquina, and Coos. In 1987, Tillamook Bay produced the most oysters, with 23,930 gallons, followed by Yaquina Bay at 12,798 gallons, Coos Bay at 3,942 gallons, and a minimal production at Netarts Bay, with 36 gallons (Carter & Lukas, 1989).

The quantity of lids discarded is unknown, but there is evidence of these lids washing up and being deposited in the estuarine muds, and some have been found after migrating out of the bays and into the nearby coastal areas (M. Graybill, personal communication, December 13, 1989).

In Oregon, our primary net fishery is the oceanic trawl fishery and the Columbia River gill and set net fishery. The gill nets are most likely to become lost, damaged, and discarded during fishing operations. Stormy weather may sink or blow them away, heavy fishing will wear and rip them, or large animals such as sharks may destroy netting. These derelict gill nets have potential for major fish losses. High (1985) found that a sunken gill net remained intact and continued fishing for more than 2 years. Trawl nets are also easily lost because they become hung up on the sea floor in trawling operations. Set nets can be lost because they are left unattended for long periods of time (Uchida, 1985), thus increasing their chance of loss. Purse seines and lift nets are the least likely to become lost when in use because they are not left unattended and will presumably not get hung up on any obstacles. For Oregon, drift gill nets and set nets are both lost in the Columbia River, and trawl nets are lost in the coastal zone primarily over the continental shelf.

Recreational Boating

In Oregon, there are 153,087 registered motorized boats, with a 6-7% increase in permits annually (Donheffner, 1988). These permits only account for registered boats in Oregon, while recreational boaters come from neighboring states to use Oregon waters, too. There are over 3.5 million recreational boat use days for 1986-87, with an average of 3 people per boat, which tallies to over 11 million people days participating in recreational boating. Of these, 63.3% go fishing, or a total of close to 7.5 million individual fishing days each year (Donheffner, 1988). These fishing outings in the three coastal regions comprise the largest number of fishing days (at 80% of the boat use days). Coastal boaters fish for salmon, steelhead, smelt, sea-run trout, onshore and offshore bottom fish, crab, and clams. An unspecified, yet certain amount of monofilament line is lost by these coastal fishermen, thus increasing the overall load of plastics in Oregon's coastal waters.

Vessel Traffic in Oregon

The overall number of vessels entering Oregon's ports is decreasing, but their size is increasing (OIWA, 1977). The total freighter and tanker trips on the Columbia River and Oregon coast (inbound only) was 2,089 in 1971, 2,407 in 1972, 2,657 in 1973, 2,053 in 1974, and 2,075 in 1975. The number of tanker trips alone was 373 in 1971, 406 in 1972, 389 in 1973, 335 in 1974, and 365 in 1975. In 1986, the number of vessel entrances in Portland over 2,000 Gross Registered Tons was 594, in Astoria it was 294, and in Coos Bay it was 199 vessels. The way in which this increase in vessel size and decrease in port entrances will affect plastic disposal practices is unknown.

Vessel Damage as an Indicator of Floating Plastics

There has been much reported vessel damage related to plastics floating in the surface layer of the ocean. By reviewing the number of encounters that vessel owners have with plastics, we can better understand the quantity of debris, although these encounters do not provide an accurate gauge of quantity or distribution. For instance, from 1984 through 1989, the Vessel Damage and Compensation Fund reimbursed Oregon commercial fishermen $347,685 for vessel damage in national waters (3 to 200 miles offshore) by fishing gear of foreign origin (B. Ford, personal communication, February 14, 1990).

Recht (1988b) took surveys at a North Pacific fishermen's conference and found that over half (64%) of their vessels had encounters with plastic debris, totalling $110,780 in damage. These plastics either fouled their propellors, fouled their fishing lines, or plugged their engine intake. Recht (1988b) followed up with another survey of commercial fishing vessel damage in Newport, Oregon. She found that 58% had encounters with plastics at sea. The damage from these encounters was estimated at $173,449, or an average of $2,725 per vessel. The majority of damage was due to net fragments and ropes entangling the propeller or fishing gear, or from plastic sheeting and bags clogging the engine intake. In another survey of sport fishermen in Oregon, Recht (1988b) found that 19% of the 1,400 recreational boats in the Port of Newport had encounters with plastic debris. The most common encounters involved rope and monofilament lines fouling the propeller or plastic bags obstructing the engine intake. These local surveys do not constitute a scientifically accurate test of the quantities, sources, or distribution of plastic, but they are believed by the author to be an indicator of the amount of plastics in Oregon's coastal zone.

Oregon Beaches

The first statewide beach cleanup was held in Oregon, October 13, 1984, with 2,100 volunteers who collected 26.3 tons of (mostly plastic) litter on 150 miles of accessible beaches. They collected 48,898 chunks of styrofoam larger than a baseball, primarily found adjacent to large rivers, especially those with marinas. They also found 2,055 strapping bands averaging about 3 feet in length; 6,117 pieces of plastic rope 1-5 feet in length; 1,442 six-pack holders; 4,787 plastic containers, many of which had foreign labels; 1,097 pieces of fishing net that weighed up to 300 pounds, found mostly by the Columbia River; 4,909 bags or sheets of plastic; and 5,339 plastic food utensils (Neilson, 1985). Generalizations that could be made were that the north coast zone, adjacent to the Columbia River, had the highest incidence of nets and styrofoam. The south coast zone was believed to receive most of its plastics from ocean drift, where the lightest debris had been blown furthest inland. In a second cleanup conducted only a few hours later on a small sample section of beach, the ratio of debris was found to be the same. This led to the conclusion that the majority of debris on the Oregon coast is from ocean drift (Neilson, 1985).

Beach cleanups have been conducted since 1984. In 1988, the most recent beach cleanup documented, there were some visible changes in the types of plastic debris found. In 1988, 2,250 volunteers collected 14.2 tons of trash, of which 70.2% was plastic. The most prevalent items by number count were: small foamed plastic pieces (13.09%), plastic pieces (10.61%), fishing and boating gear (7.45%), galley wastes (7.43%), miscellaneous plastic bags (7.12%), bottles (6.42%), plastic caps and lids (5.57%), plastic foam cups (3.92%), plastic trash bags (3.19%), plastic rope 2 feet and longer (3.18%), plastic utensils (2.49%), operational wastes (2.02%), sewage related plastics (.21%), and medical wastes (0.07%) (O'Hara et al., 1989). In this cleanup there were many reports of wildlife entanglement: gulls were found in plastic ropes and others with plastics in their mouth, and numerous dead birds were entangled in lines.

On the beaches, the majority of plastic that washes ashore is positively buoyant, such as items like styrofoam, utensils, and containers. When storms blow over Oregon, much of the debris that floats is washed ashore, while negatively buoyant plastics will wash up in smaller proportions.

Marine Mammals

Mate (1985) has surveyed Oregon beaches since 1968 and reports in his examination of over 200 beach-cast pinniped carcasses that only one Steller Sea Lion had neck lacerations related to net entanglement. In his survey of 3 rookery sites, he found 2 Steller Sea Lions with visible neck lacerations, and in the following 3 years he found 9 of 158 identifiable sea lions that showed neck wounds typical of net entanglement. O'Hara et al. (1986) report that in Oregon, Harbor Seals are most frequently entangled in nets, but the California Sea Lion, Steller Sea Lion, Northern Fur Seal, Elephant Seal, and assorted cetaceans have been entangled (See Table 11). Scordino and Fisher (1983) have noted Northern Fur Seal entanglement in Oregon, with seals caught in heavy pieces of trawl mesh in 1980 and 1982. R. Lowe (personal communication, December 1989) reported one adult Northern Sea Lion observed at Rogue Reef with a large ball of trawl netting wrapped around its head and neck.

Cetaceans on Oregon Coast

Mate (1985) has also observed marine mammals that have been entangled in plastic netting and lines. Gray whales were the species most commonly entangled in fishing gear,

TABLE 11. Estimated Populations of Pinnipeds on the Oregon Coast

Species	Date	Population	% Change	Distribution
Harbor Seal (Phoca vitulina)	2/85	5325	6-8% inc.	year round
California Sea Lion (Zalophus californianus)	9/84	1938	increasing	seasonal
Steller Sea Lion (Eumetopias jubutus)	5/84	2352	no change	year round
Northern Elephant Seal (Mirounga angustirostris)		< 10	increasing	seasonal
Northern Fur Seal (Callorhinus ursinus)				seasonal

Note. From Assessment of Pinniped Populations in Oregon: April 1984 to April 1985 (NWAFC Processed Report 88-05) by Robin F. Brown, 1988, Newport, OR: National Marine Fisheries Service.

usually in areas with crab pot lines. In all cases the plastic rope was caught between the whales' baleen plates, indicating that the entanglement probably occurred while the animals were surfacing. In the whales' struggle to disengage themselves, the rope often further entangled their flukes and flippers (O'Hara et al., 1986).

In 1976-1978 an experimental crab fishing technique was conducted off Oregon where the conventional crab traps were modified with a longer line between the two buoys. In this period 5-8 Gray whales were entangled annually during their migration. In 1983-1984 on the Oregon and Washington coasts, 27 gray whales were entangled yearly, and not only in crab pot lines (O'Hara et al., 1986). Mate (1985) estimates that an average of 2 Gray whales per year become entangled in crab pot lines, but other species have also been spotted in the same predicament. He has also found a Minke whale entangled with a crab pot line worn through its mouth down to the jawbone. Other isolated incidents have also occurred; for example, a whale's entanglement in a fishing net was reported at Winchester Bay in July of 1989.

Oregon Seabirds

Oregon is host to numerous breeding seabirds, although six species comprise 99.5% of the population. Twelve species breed along the Oregon coast, nesting on offshore islands and on the mainland in areas removed from human interference. Of seabirds, sooty shearwaters, Leach's storm petrels, Brandt's cormorant, and the common murre are estimated to consume 125 million pounds of pelagic fish annually off Oregon's coast (Baily & Parmenter, 1985). This represents 22% of the annual production of small pelagic fish, and thus ingestion of plastics may be significantly frequent among these species. Leach's storm petrels and common murres account for 94% of the breeding population (see Table 12). Leach's storm petrels, Oceanodroma leucorhoa, represent 51%; common murres, Uria aalge, 43%; Brandt's cormorant, Phalacrocoax penicillatus, 2%; western gull, Larus occidentalis, 1.5%; pelagic cormorant, Phalacrocorax pelagicus, 1%; tufted puffin, Lunda cirrhata, 1%; and other species (Cassin's auklet, Ptychoramphus aleuticus; rhinoceros auklet, Cerorhinca monocerata; pigeon guillemot, Cepphus columba; black oyster catcher, Haematopus bachmani; double-crested cormorant, Phalacrocorax auritus; and glaucous-winged gull, Larus glaucescens), 0.5% (Graybill, Hodder, & Pitman, in press).

TABLE 12. Estimated Breeding Population of Seabirds on the Oregon Coast

Species	Breeding Population
Leach's storm petrel	354,412
Common murre	297,227
Brandt's cormorant	15,932
Western gull	9,846
Tufted puffin	6,560
Pelagic cormorant	6,321

Note. From Catalog of Oregon Seabird Colonies by M. Graybill, J. Hodder, and R. Pitman, in press, Portland, Oregon: U.S. Department of Fish and Wildlife.

In Oregon, qualitative reports have been made about seabird ingestion and entanglement, although no quantitative estimates have been derived. Bayer and Olsen (1988) found three northern fulmars that contained plastic. Each fulmar had ingested an average of 2.7 plastic particles, all of which were positively buoyant. Only one piece of plastic was a pellet (4 mm x 2 mm x 2 mm), while the others were larger fragments (8-14 mm x 2-9 mm x 1-4 mm). Plastics have been found in other northern fulmars elsewhere: Day et al. (1985) found an average of 2.8 plastic fragments in Alaska; Baltz and Morejohn (1976) found an average of 11 plastic fragments in California; and van Franecker (1985) found an average of 12 plastic fragments in the Netherlands and also an average of 4-5 fragments in the arctic Atlantic ocean.

Other species of birds have been known to ingest plastics in Oregon. Varoujean (personal communication, January 1990) found approximately 0.001% of plastics in stomach analyses of 800-900 common murres. He also found a noticeable but undetermined quantity of plastic in sooty shearwaters' stomachs. Mathews (1987) found an unquantifiable amount of plastic particles in sooty shearwaters, too, all of which were collected 3-27 km offshore.

Studies in Oregon regarding seabird ingestion are nominal, while findings of seabird entanglement are more prevalent. The author has observed entangled common murres and gulls (approximately five) on the Oregon coast in the previous few years. R. Lowe (personal communication, December 1989) has conducted weekly transects between Seal Rock and Alsea Bay from May through October. In 1986, he found two common murres dead and entangled in commercial salmon fish gear. In 1987, he found one dead surf scoter entangled in a large monofilament gill net that had been adrift for many months. In 1988, he observed one western gull entangled in monofilament line, one dead western gull entangled with a rubber band, one pelagic cormorant entangled in commercial fishing gear, one dead pelagic cormorant snagged by hook and line, one common murre entangled in a six-pack ring, and one sooty shearwater containing eight plastic fragments in its gizzard. In 1989, he noted one pelagic cormorant caught in a commercial salmon jig and one common murre entangled in sport salmon gear. In four years of personal observations on one 4.4 km stretch of beach, R. Bayer (personal communication, December 1989) found 5-20 birds that had been entangled. Most recently he found a black oyster catcher caught in monofilament line. O'Hara et al. (1986) reports numerous entangled birds from beach surveys found in fishing line, plastic vegetable sack, cassette tape, kite string, plastic rope, and swallowed plastic.

Conclusion

Monitoring impacts on wildlife is difficult to gauge because many mammals and birds disappear at sea, never to be observed by humans. The carcasses of dead marine life may sink quickly out of sight or decompose quickly on the beaches once deposited. The amount of plastics sinking in the water column is also hard to determine, thus limiting estimates to visual observations. Currents within 1-2 km of shore may respond very differently and with great flux when compared to the overall oceanic circulation patterns of the North Pacific. This variance of near-shore currents may limit the current generalizations that we can apply to Oregon, thus altering the actual distribution patterns of plastics in Oregon's near-shore coastal waters.

This study was limited by an overall lack of data for Oregon. Quantities and distribution of plastics were inferred from other regional data, and impacts to wildlife were limited to infrequent accounts from field biologists and a few government reports.

This thesis has identified qualitative impacts of plastics to particular individuals and species within the marine ecosystem. Overall population and community effects of plastics are too difficult to predict at this time, as in Alaska with the Northern Fur Seal and in Hawaii with the Hawaiian Monk Seal. Further investigation of specific impacts of plastics to Oregon's wildlife should be pursued immediately to determine if greater impacts are occurring on a population level, and not just on an individual level. I recommend increased funding for research to determine the Oregon-specific sources, quantities, and distribution of marine plastics, and further study on the cumulative impact of plastics to Oregon's marine wildlife.

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