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Research on the Use of Degradable Fishing Gear and Packaging Materials

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Research on the Use of Degradable Fishing Gear and Packaging Materials

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1.0 Introduction

Since the presence of plastic debris was first recorded in the marine waters in the early seventies (Carpenter and Smith, 1972), numerous observations on plastic pollutants have been made in various oceans of the world. These include the Northern Pacific (Merrel, 1980), Newfoundland coast (Perkins, et al., 1979), Western Australia (Anon., 1977), South Africa (Shaughnessy, 1980), Atlantic Ocean (Colton, et al., 1974), New Zealand (Gregory, 1978), Mediterranean (Morris, 1980), Lebanon (Shiber, 1979), Costa del Sol in Spain (Shiber, 1982), and other locations. Most such litter is associated with the northern hemisphere at this time, but with increasing use of plastics worldwide the problem of plastic litter at sea is destined to be a global one.

Several beach surveys as well as ocean observations of the debris has been carried out at different locations. Clearly, the plastic debris constitute a very significant fraction of the total material collected or observed. [This is hardly surrising; in 1975 the National Academy of Sciences estimated that commercial fishing fleets alone lost nearly 150,000 tons of plastic fishing gear annually (NAS, 1975).] For instance the 1985 Oregon beach clean-up effort found plastic items to be the most frequent type of litter (foamed polystyrene, plastic rope, strapping bands, webbing and six pack yokes in decreasing order of frequency of occurrence) (Nelson, 1984). The Amchitka beach survey by Merrel (1984) found trawl web, gill net floats and strapping to be the main debris items. Observations of floating debris at sea has also been made by several workers (Low, 1983; Dahlberg, 1984; Jones and Ferrero, 1984). Recent reviewers (Ribic & Bledsoe, 1986) have pointed out the limitations of the existing beach survey and observer data, particularly with respect to the sampling intensity and spatial coverage. Nevertheless, the data, at least qualitatively, illustrates the extent of the problem of plastic debris in marine environment.

The manufactured plastic materials that are likely to end up as marine debris might conveniently be classified into three groups.

Group 1 (Floating Non-Net Debris)

The packaging materials: bags, strapping, bait boxes, plastic ropes, cups, bottles, net floats, buoys, etc. Mainly made of foamed polystyrene, polyethylene, and polypropylene.

Group 2 (Sinking Debris)

Gill net related materials: nylon monofilament or multifilament netting, crab pot webbing, etc.

Group 3 (Floating Debris)

Trawl webbing material: polyethylene and polypropylene webbing materials.

Note that Group 2 materials do not often turn up in beach surveys. Merrell (1984) lists common plastic litter on American beaches. These are seen to be exclusively group 1 and 3 material.

Apart from the general undesirability of floating debris at sea (from an aesthetic point of view), the debris often poses a threat to a wide variety of marine life. Numerous observations and studies on several species of animals demonstrates the hazardous nature of particularly the Group 2 and Group 3 debris. The following is a non-comprehensive listing of such studies which illustrate the diversity of animals affected by the debris.

Andre & Ittner	1980	Hawaiian Monk Seal
Balasz	1979	"
Fiscus	1978	"
Beach, et al.	1976	Aleutian Reindeer
Bigg	1979	Northern Fur Seal
Bonner	1972	"
Brongersma	1968	Sea Turtles
Duguy, et al.	1980	"
Duron & Duron	1980	"
Hughes	1974	"
Fledkamp	1983	Sea Lions
Calkins	1985	"
Kenyon & Kridler	1969	Laysan Albatross
Pettit	1981	"
Bourne	1976	Marine Birds
Day	1980	"
Gochfeld	1973	"
Rothstein	1973	"

The nature of the hazard varies with the species. In the case of otters, sea lions, etc. the net fragments and strapping bands tend to entangle or "collar" the animal. This often leads to strangulation or severe physical damage, as the plastic cuts into the skin of the growing animal. In the case of marine birds and the sea turtles, the debris plays an additional subtle role. These animals may confuse the debris with food species and ingest them (e.g. sea turtles may confuse plastic bags with jellyfish). Day (1980) found the appearance of the ingested debris to be somewhat similar in appearance to the regular food species of the bird.

Even more important is the incidental catch of fish claimed by the net debris and abandoned/lost complete gear at sea. The nylon nets and fragments sink in sea water. (This perhaps explains Merrel (1984) observation that beach surveys record numerous gill net floats but very few gill net sections. Unlike the floats, the gill nets are denser than water.) The fishing efficiency of the net depends to a great extent on the configuration of the net underwater. Canadian research on the quesion suggests (Way, 1977) that lost nets do continue to fish at undetermined rates for extended periods of time. Carr (1984) surveyed east coast Stellwagen Bank area fishery using a submersible. In 100 acres of active gill net fishing area, 10 ghost nets were located. Four of these had vertical configurations 10-36 square feet in area while four more were of low vertical profile (less than two feet) and 200 to 750 feet long! It is significant that even after a period of two years underwater (estimated from bryozoan growth on nets), the gear was still partially functional and did show evidence of ghost fishing. These observations agree with those of High (1981) who studied the derelict gill nets near wrecks. Vessel wrecks being good breeding grounds for fish, are attractive sites for gill netting in spite of the higher probability of entanglement of gear on submerged structures.

Even completely horizontally laid out gill nets pose a hazard to some marine inhabitants such as crabs. [Active sunken gill nets in Alaska are required to be 18 inches above the bottom to facilitate the passage of crabs (High, 1985).] Furthermore, there is also no evidence to believe that the gear once in horizontal position will continue to be so in spite of the currents, wave action, and movement due to entangled species.

A gear of particular interest in this connection is the crab pot. These small gear have a particularly high incidence of loss. In the King Crab fishery in the Alaskan waters High (1979) estimated the gear loss to be as high as 10%. When one considers the size of the fishery and the fact that crabbing at that location has continued for a quarter of a century, the quantity of derelict crab pots which might still be entrapping crabs can be readily appreciated. Recently it was shown that a significant fraction of both the King and the Dungeness crabs failed to escape from unbaited pots at all and that confinement in such derelict pots for a period exceeding 10 days before release contributes to increased mortality of the release animals (High, 1985).

It is clear that the existence of derelict gear and gear sections among the marine debris pose a threat to some forms of marine life. The studies up-to-date seem to also indicate the "ghost fishing" by such gear resulting in a threat to the fishery itself. How might the threat due to plastic debris be neutralized?

Recent discussions on the subject has essentially suggested (Workshop, 1984) several ways of mitigating the threat. These include (a) education of the fishermen and other users of the marine environment in an effort to reduce the influx of debris into the sea; (b) regulation of disposal of debris at sea; and (c) investigation of the feasibility of use of degradable fishing gear.

Education of fishermen (and the general public) to increase their awareness of the threat to marine ecosystem posed by plastics, is undoubtedly a productive exercise. However, this strategy alone (or a and b above toge-together), does not fully address the problem. Not only can 100% compliance not be expected, but the very significant fraction of debris consisting of lost gear, is not addressed by these two proposed strategies alone.

This study is a preliminary attempt at determining the feasibility and practicability of rendering various fishing gear rapidly degradable on being lost or abandoned at sea. The crucial technical issue involved is to determine if the technology exists to render the gear degradable on loss/-abandonment without any risk of premature degradation during normal use. Any candidate technology also has to yield non-toxic products of degradation, non-impairment of the "catchability" of gear and minimal increase in the cost of treated gear.

2.0 Gill Net and Trawl Fisheries

2.1 Application of Gill Nets and Trawls

The salmon fisheries off the coast of Alaska offers an excellent example of the efficient use of gill nets in commercial fishing. Fishing is carried out extensively in nine fisheries and the target species include the pink, sockeye, chum, coho and chinook salmon. The length of the gear, the depth (meshes) and the mesh size is often regulated by the state.

Gill nets are also used in California where the target species include shark, halibut, swordfish, rock cod and others. Both monofilament and multi-strand monofilament gear is used with the former becoming increasingly popular. Gill netting might be carried out throughout the year in this fishery as the fishing seasons for various target species are well spread out throughout the year. The same gear is sometimes used for several different species with the result that the gear is in water most of the year and is generally worn out faster. Where a gear is used for a single species only, it is brought to shore and stored in a net loft until the next season.

Also of interest is the California Herring Fishery. Set netting, [where the gill net (or a string of nets) is set at the ocean bottom and anchored at each end], is the only method allowed for gill netting herring in San Francisco Bay, Tomales Bay and the Bodega Bay. The monofilament nylon nets used are usually replaced every season. The duration of the season itself is short, extending for about 3 months or so during December until March. Fishing begins whenever a spawning herring run appears and continues daily until the run is over. Spawning runs are of short duration, lasting one to four nights. This allows the fisherman approximately 7-9 runs for the entire season. The nets are set when the herring is found; the gear is therefore exposed to the water for relatively short periods of time.

Drift gill netting [where a series of nets suspended (usually by means of strops from buoys) below the water surface, is allowed to drift in the ocean, secured to a fishing vessel], is also popular off the California coast. Sword fish and sharks are caught with this gear. Nets often remain in the water overnight and are stored aboard the vessel while the catch is being delivered to the shore. (This is an ocean fishery and vessels go out for several days at a time).

In addition to the above mentioned American gill netting activity, a considerable amount of foreign gill netting also occurs in the mid Pacific. Japanese pioneered the method for fishing salmon and used it for many years extending back beyond World War II. The Japanese as well as the other Asians (Taiwanese, Koreans, etc.) extensively fish the mid-Pacific waters using this gear. Any abandoned gear from these sources may easily end up in US waters due to the action of currents. Gill net floats from these foreign sources have been observed on the US and Canadian shores. Uchida (1984) has discussed the world wide use of gill nets and related gear.

Gill net is placed in the path of fish and entraps the fish in three ways; (a) wedging the fish within the mesh; (b) gilling the fish with the twine caught beneath the gill flap and (c) tangling, where the fish has not penetrated the net but is caught by teeth, fins, etc. The size distribution of the fish caught in the gear is determined, as might be expected, by the mesh size. Hamley (1975) has reviewed the literature on the size distributions and the related mathematical models. Often the distributions are gaussian with a slight skew to the right.

The chances of loss (or abandonment) of a gill net is somewhat higher than that of other gear. The drift nets might be torn by vessels moving over them, by larger marine animals, large submerged debris, etc. The gear might also be torn during hauling especially when loaded, and is particularly sensitive to stormy weather when the whole drift net (or even set net) might be lost. Due to the relatively low cost of the gear, it is unlikely that much effort is directed at locating and recovering the lost gear (though some fisherman claim otherwise). Larger pieces of gill netting sinks in water and is therefore difficult to retrieve. In the case of the popular monofilament gear, it is perhaps not even worth recovering torn net segments as it is quite difficult to repair a torn monofilament gear effectively. In some fisheries (such as Bristol Bay), the fishermen often have to fish within a short time period. Working against the clock, the gear sometimes might be cut off when entangled to save the fishing time and effort. It is essentially a short lifetime gear (or even a seasonal one) compared to trawls.

Furthermore, the amount of gill nets used in the North Pacific, far outstrips that of seines, trawls and miscellaneous gear. Uchida (1984) estimates 3-5 million units of gill nets to be available to major fisheries.

Icelandic cod fishery illustrates the numbers of such gear involved. This short-term (4-month) fishery is fished by gill netters, each using about 100 nets/day. Since the gear is short-lived, each boat may use up to 400 nets/season (Frechet, 1964). Bad weather and heavy fishing are responsible for the short life-span of the the gear.

Coastal trawl fleet in the U.S. and Canadian Pacific coast consists of a mixture of vessels; these include year around trawlers, seasonal trawlers and part time trawlers. Lippa (1967) has reviewed the Canadian trawl gear. The U.S. fleet of high seas trawlers actively fish halibut in the Bering Sea. The target species in trawl fishing also includes perch, flatfish, pollock, sablefish, shrimp, etc.

As in the case of gill netting, a substantial foreign fleet operates off the American coast. The extent and the nature of their operations has been recently reviewed by several workers. French, et al. (1981), Wall, et al. (1981), Nelson, et al. (1981).

Trawl is a precisely designed, bag-like gear with a large mouth and a gradually tapering body. In mid-water or pelagic trawling, the gear is directed at schools of fish detected using acoustic instruments. The material requirements for the construction of mid-water trawls are rather specific and must take into account the special requirements in terms of tenacity, elasticity, and wet-knot breaking strength (von Brandt & Klust, 1971).

The bottom trawl is often dragged over rough ocean bottoms at high speeds. The underside of the gear, often termed the "belly" is particularly susceptible to damage where the trawl gear is used for bottom trawling. This may often lead to either severe damage or complete loss of the gear. The highest likelihood of such "hanging up" of demersal trawls occur during the preliminary, exploratory stage of the fishing operation when the fisherman is unfamiliar with bottom characteristics. Low, et al. (1984) has estimated the loss of trawl gear (nets or large portions of nets) in foreign and joint-venture operations off Alaska in 1983 alone to be as high as 65.

Due to the particularly high likelihood of gill nets and trawls ending up as marine debris, emphasis will be placed on these two types of gear throughout this report.

2.2 Fisheries Operations Selected for Field Study

The field study consisted of carrying out interviews with fishermen, gear marketers and other personnel in order to obtain firsthand data on the practices of gear usage in various fisheries. Therefore it was crucial that the sample of fishermen to be interviewed be selected in a manner to be representative of the total local gill net and trawl fishery. This was achieved through the guidance provided by a Fisheries Consultant hired for the purpose. Having taken into consideration the various gill net and trawl fisheries in the west coast, the relevant fishing seasons, the target species and the ethnic origins of the fishermen, the following fishing areas were selected as being representative of the west coast.

Bristol Bay
Prince William Sound
Southeast Alaska
Puget Sound
Columbia
San Francisco
San Pedro
San Diego

While the project focused on the west coast fishery in particular, some information relating to the east coast cod fishery was also obtained. The fishermen who fish in the Alaskan waters are often located in the greater Seattle area where some of the interviews were carried out. The interviewer traveled to California locations for the rest of the interviews. The person who carried out the interviews was a retired professional fisherman (having fished in the west coast for over fifty years). While this might have introduced a slight degree of bias into the interviews and reporting process, the choice was a good one in terms of obtaining information from fishermen. Not only was he (and his former vessel) well known in some of the fisheries, but he spoke a common language with others in the same trade. Fishermen were found to be generally wary of giving out information to strangers, particularly when they might be scientists (possibly connected with regulating agencies). Some groups of fishermen (of non-American ethnic origin) did not take part in the interviews claiming a limited knowledge of the English language!

The interviewer usually worked from a set of questions prepared by the consultant used on the project. These questions sought answers and relevant data on the following subject areas.

1. Identity of fisherman and fishing experience
2. Nature of vessel
3. Deck machinery
4. Salmon drift net operation

   Frequency of usage of gear in a season
   Weather during season
   Where fishing was carried out
   Catch size
   Estimates of extent of exposure of net on deck (covered and uncovered).
   Repair (frequency and where the work is carried out)
   Frequency of and causes of gear loss. Places where lost gear was recovered.
   Description of any recovered gear which was abandoned/lost

5. Salmon set nets (above data)
6. Other species drift nets (above data)
7. Bottom set nets (above data)
8. Bottom and midwater trawls (above data).

Interviewees were not required to answer all the questions; most declined to answer some of them. Often the answers had to be deduced from general comments on the subject as the interviews were not structured as orderly question-answer sessions.

Generally the interviews yielded valuable first-hand information on gear use and also served to illustrate the attitude of the fishing industry towards the plastic debris problem.

Several net marketers/manufacturers were also consulted as a part of the study. Several of these latter consultations were carried out by means of telephone interviews. But at least two of these were interviewed in person by the interviewer in Seattle.

2.3 Study of Typical Gear Use

The main objective of the interviews was not to obtain general statistical information on the relevant fisheries. The sample size employed was too small and the techniques used were not suited for that purpose. The exercise, however, was expected to yield specific pieces of data on the gear usage to enable evaluation of various approaches to enhanced degradability, from a practical point of view. To this end, the data relating to following questions are the most significant.

a. Gear construction (plastic type, mono/multi/braid & twist etc.)

b. Level at which gear is used underwater.

c. Approximate days gear is on board, in water, on deck and in storage.

d. Years of life with repair.

e. Approximate value of a single unit of gear (netting).

The data relating to the above has been summarized from various interviews and other contacts carried out mainly in the west coast area (see Table 2.1).

The lifetimes of the gear shows several interesting groupings. The nylon gill nets are quoted lifetimes with repair to yield a conservative over-estimate. Herring nets made of monofilament nylon, for instance,

Table 2.1. Approximate Range of Time Usage and Values of Single Units of Fishing Gear Made of Synthetic Netting.

Type of Net	Material	Construction	Fishing Area	Fishing Level	Season[a]	Days Aboard[a]	Days in Water	Days on Deck	Months in Storage	Years of Life With Repairs	Value of Netting (1 unit)[a]
Salmon Gill Net	nylon	monofilament	WA	Surface Drift	July-Nov.	40-120	16-45	24-74	6-8	1-3	$ 825
Salmon Gill Net	nylon	monofilament	Oregon	Surface Drift	July-Oct.	4-40	2-10	2-30	6-8	1-3	825
Salmon Gill Net	nylon	multi-mono-filament	Alaska	Surface Drift	May-Sept.	30-120	16-38	14-84	6-8	1-3	385-1116
Herring Gill NEt	nylon	monofilament	CA	Bottom Set	Dec. Mar.	30	4-10	26-20	11-12	1-2	385-825
Herring Gill Net	nylon	monofilament	Alaska	Bottom Set	Jan. Jun.	30	1-4	29-26	10-12	1-2	385-825
Bottom Fish Gill Net	nylon	monofilament	CA	Bottom Set	Year Around	300	100-200	200-100	4-6	1-7	100-825
Swordfish/ Shark Gill Net	nylon	multi-mono filament	CA	Surface Drift	Year around	300	100-200	200-100	4-8*	1-7	500-1500
Bottom Trawl	Nylon-poly.	Braid & Twist	US & Alaska	Bottom	Year Around	100-325	50-275	50-50	4-8*	1-10	1,000-10,000
Mid-water Trawl	Nylon & Poly.	Braid & Twist	US & Alaska	Pelagic	Year Around	100-325	50-150	150-50	4-6*	1-10	4,000-18,000
Shrimp Trawl	Poly & Nylon	Braid & Twist	US & Alaska	Bottom	Year Around	100-250	50-200	50-100	4-8*	1-7	1,500-8,000
Crab Pots	Nylon & Cotton	Twist	Alaska	Bottom	Year Around	100-250	50-125	50-125	4-6*	1-3	20-50

* Vessel Owner may engage in another method of fishign and store listed gear for several months.

[a] Approximate

Note: Vessel owners may quit one method of fishing for 1-3 years and put gear in storage and then return to method later or sell gear to someone else.

Note: While only single gear units are shown, vessels are equipped with as many complete nets and as much spare netting as needed and fish as many as regulations and budgets allow.

are rarely repaired and used a second season. Even the monofilament salmon nets, according to experts, are best replaced every year or when 100,000 pounds of fish have been fished using them (Talley, 1983). This allows classifying the gill nets in major fisheries by lifetime.

Herring gill nets (monofilament) when actively used are replaced at least once in two years or probably every year. The monofilament salmon gill nets have a slightly longer life span of three years (with even possible replacement every year). The bottom set nets in shark/swordfish fisheries (and other fish except herring in California) seem to have a longer lifetime of one to seven years. The identification of the lifetimes is crucial in the design of enhanced degradable gear to ensure that there is no chance for the treated gear to prematurely fail (degrade) while in use.

A second important consideration is the extent of exposure to sunlight and to water, during its lifetime. With the exception of the bottom set nets, the gill nets have a limited annual exposure of a maximum of about 2 months in water, mostly due to seasonal restrictions. Trawls which are used year around are in water for longer periods of time, up to 9 months a year. The time of exposure on deck is given in the table to indicate approximately the extent of exposure to light. Due to wide variations in practice and the limited amount of data available, it is difficult to estimate the fraction of time the gear is kept covered. It is, however, likely that the trawls receive slightly greater exposure than the gill nets.

2.4 Comments of Fishermen's Awareness of the Damage to Marine Ecosystem by Plastic Debris

Fishermen as a group are the most intimately associated with the marine environment. Therefore, it is important that they understand the implications of derelict plastic gear and other debris at sea. An attempt was made to determine their views on the topic of lost/abandoned gear. These questions were aimed at finding the fishermen views of the following.

a. Fate of an abandoned/lost net

b. Reasonable length of time after which there is no further concern over lost nets causing any harm to marine animals.

c. Views on degradable gear.

They were also asked if they had observed either marine animals entangled in nets at sea, or plastic net fragments on beaches.

The general response to the above was that most of the fishermen believed the net to ball up due to the wave action, on being abandoned. Since the net in such a tight configuration is not effective in fishing, they claimed the lost gear to be no threat to marine life even immediately after the loss. They thought the degradable gear to be an expensive solution to an ill-defined problem. None of those interviewed admitted to seeing any entangled marine animals. Most have not seen any webbing on U.S. beaches.

The netting debris on beaches, where these might have been observed, was attributed by the fishermen to either (i) material drifting in shore from Japanese/Asian fleets; or (ii) material remaining after a gear repair job which is often done on beach.

It was clear that the fishermen were unaware (or did not want to admit that they were aware) of the serious implications of lost or abandoned gear. However, they readily admitted that dumping plastic debris such as cups, boxes, bags, etc. should be controlled. This practice was also attributed in part to activities of sport fishermen and boating enthusiasts. Fishermen in general felt that the practice could be stopped without much effort by a suitable control/regulatory strategy.

In the analysis of the interview data, the fisheries technology consultant on the project pointed out that the actual number of gear lost was negligibly small compared to the total gear in use. By assuming the number of boats, average numbers of nets and a hypothetical fractional loss factor, the number of lost gear might be estimated approximately. By reducing this number by a suitable factor to take into account the reduced fishing efficiency of folded (or "balled-up") gear underwater, a very small quantitative estimate of active derelict nets can indeed be obtained.

However, such estimates suffer from two drawbacks. (a) The accumulation of gear in the fishery over the years is not taken into account and (b) the fact that, unlike active gear, the derelict gear fishes 24 hours a day, throughout the year is not taken into account.

The lack of appreciation of the magnitude and the seriousness of the problem by fishermen is unfortunate. Perhaps, the interviewees felt that admitting to the existence of the problem might result in some regulatory action which might subsequently lead to a financial loss to them personally. Some, fishermen that the author spoke to felt the larger marine animals (sea lions, seals) to be a definite hindrance to profitable net fishing. These animals are known to feed on gill net catches and occasionally to damage gear.

3.0 Plastics in Fishing Gear Manufacture

Plastic fishing gear is clearly superior in both strength and durability, to the natural-fiber-based gear that it replaced. This enables the gear to be left unattended in water for extended lengths of time, or to be stored over a period of non-use, without risking deterioration. The high breaking strength, low water-resistance and good optical clarity (in water), of these materials has improved the "catchability" of gear in major fisheries. These features probably account for the rapid, industry-wide change-over to plastic gear about 1966.

However, the plastic fishing gear suffer from several disadvantages. Plastics are not only expensive, but in some instances (like in monofilament gear) is difficult to repair. The twine would damage the catch by cutting into the fish in the case of "soft" fishes such as herring.

The major drawback from an ecological point of view, however, is its longevity as a fishing gear in the event that it is discarded or lost at sea. The sections of "ghost nets" would then continue to fish and also pose a hazard to various forms of marine life.

This report has identified (a) gill nets, (b) trawls and (c) crab pots as being the most likely gear to be abandoned, lost or damaged at sea. Therefore the type of plastics used in these gear are of special interest.

3.1 Types of Plastics in Fishing Gear

The plastic fishing gear used both in west coast and east coast fisheries are imported from Japan (and to a lesser extent from Korea and Taiwan). Gear marketers estimate that at least 90-95% of gear used in the west coast fisheries originate in Japan.

Gill Nets

Being a passive gear which is merely placed in the path of a moving school of fish, a fine, transparent type of material is advantageous in the construction of gill nets. The netting must also be tough, with adequate elasticity to hold a gilled fish securely during the hauling process.

These characteristics are best found in nylon (polyamide) gear - particularly the monofilament gear which is nearly invisible in water.

Nylon (polyamide) gear is extensively used in the gill net fisheries for salmon, cod, mackerel, herring, halibut, shark, swordfish, albacore, rockfish and sea bass.

Bottom Trawl Nets

Of all fishing gear, bottom trawls suffer the most abrasive damage as well as wear and tear during use. As such, replacement costs of particularly the underside of gear, is often high. This has lead to the use of more economical polyethylene (or polypropylene) yarns for this application. The buoyancy of polyolefin nets is also believed to help in limiting the damage to gear on dragging over a rough bottom.

The more expensive nylon yarn is superior in terms of having both a better "wet knot strength" (about 5-10% higher than for polyolefins) and are about 20% lighter than polyethylene monofilaments.

Often, the gear represents a compromise with the bulk of the gear being made of polyolefin yarn and the cod-end area being made of nylon yarn.

Pelagic Trawl Nets

These operate in mid water and in terms of material characteristics demand about the same specification as bottom trawl nets. They are usually of larger mesh size and are designed to cause a minimum disturbance inthe water they are dragged-in. Netting yarn is usually fine and strong.

These requirements are best met by monofilament of multifilament nylon (polyamide material, widely used in the construction of this gear).

Crab-pots

Crab-pots generally of steel construction with multifilament nylon and cotton fiber netting is a sedentary gear. The toughness of the plastics material and perhaps its invisibility is the main requirement here. These are served by nylon well enough. The cotton strands are often used on one end-side mesh of the gear.

3.2 Technical Feasibility of Degradable Plastics

The particular plastics employed in outdoor application are often selected on the basis of their superior weather-resistance. Furthermore, the plastic material is so formulated (mixed with a variety of additives) to minimize any effects of light or heat-induced damage. Consequently, while a very slow deterioration process does take place in all plastics used outdoors, the life time of these materials are astonishingly long. Due to their extreme slow biodeterioration in both soil and in sea water, they are virtually indestructible outdoors, particularly when protected from light.

In the marine environment, plastics are exposed to several stresses which influence the rate at which they deteriorate.

(i). Water

While nylons and polyethylenes are hydrophobic (the latter more so than the former), they do absorb moisture. Laboratory studies have shown the presence of moisture to generally accelerate the degradation of plastic materials (Davis and Sims, 1983). However, this is hardly a significant factor in comparison to the particular effectiveness of light in bringing about degradation.

(ii). Light

Sunlight received at earth's surface includes ultraviolet (UV) light in the wavelength range 290-340 nm. The shorter wavelength UV light (about 290-315 nm), sometimes referred to as the UV-B region, is particularly harsh and leads to rapid deterioration of plastics. It is the relatively low concentration of UV-B in sunlight, amounting to less than 1% of total irradiance, which allows plastics to be successfully used in outdoor applications.

Light-induced damage is auto-catalytic (the products of degradation reactions catalyze or lead to further degradation). The principal effect is a severe loss in the mechanical properties (such as strength, hardness, and flexibility) of the plastics (Hawkins, 1984).

In the marine environment, UV-B radiation is fully available at the surface of the sea only. On passing through sea-water it is rapidly attenuated, dropping to negligible levels at a few meters depth.

Thus most gear in their normal use at sea is protected from the UV light. (Perhaps the only exception is the beach set nets). However, on being lost or damaged, netting made of materials less denser than water (polyolefins) will float in water and be exposed to UV-light. Even while floating, the rates of light-induced degradation in polyolefins is a moderate to slow process, thanks to the stabilizers used in their manufacture. Also, plastics floating at sea are continually cooled by the mass of water and held at relatively low temperatures; a factor which accelerates light-induced deterioration of plastics on land is the concurrent heat build-up increasing the temperature of plastic. As with most other chemical reactions, degradation of plastics is also accelerated at the higher temperature.

Nylon materials are usually denser than sea-water and will not float. Any degradation mechanisms based on light cannot therefore be used to achieve rapid degradability in nylon gear. (The fact that nylon netting sinks in water does not necessarily make it less hazardous than polyolefin webbing to marine animals. However, since it does not float, these nets are not encountered in beach survey exercise and might not be readily recognized as plastic "debris").

(iii). Microbial Attack

During regular usage, fishing gear is routinely set in water and hauled on deck where it may dry off relatively fast. Such cyclic wetting/drying may make it difficult for the various microbes and marine fauna to grow on the gear.

In the case of lost/abandoned gear; however, the extended "wet-time" at sea should promote microbial growth. However, the importance of this factor in causing degradation is rather limited perhaps due to the fact that plastics do not represent an accessible nutrient (carbon or nitrogen) source to most microbes.

The general subject of microbial degradation of plastics is not well understood at the present time. (This is even more true of biodegradation in the marine environment.)

Of the factors considered above, it is clear that light is the most important one. Light is available, unfortunately, only to floating debris such as trawl webbing made of polyolefins, miscellaneous plastic bags, bands, containers, etc. Even in the case of these materials, the light induced degradation found in nature is too slow a process to depend on to reduce hazards to marine life.

However, the rate of degradation by light and also that due to microbial attack might be accelerated. In most cases this involves the use of additives which are added to the polymer at the processing stage to make it susceptible to accelerated degradation. Since the rate of such degradation depends upon the concentration of the additive used, some degree of control of the lifetime of a plastic used outdoors can usually be achieved. The additives used at low levels should not affect either the mechanical or processing characteristics of the plastic material.

The ability to control the lifetime with a high degree of reliability is crucial in the case of any enhanced degradable fishing gear. The standard gear of interest to the present study, such as gill nets and particularly trawls, are expensive. Premature failure of these materials due to built-in enhanced degradability (particularly during a good catch) is quite unacceptable. Fortunately, the service life of a fishing gear is much shorter than the natural lifetime of the plastic from which it is constructed, enabling effective use of these technologies to render plastics biodegradable.

Specific available technologies which depend on the two approaches (photodegradation and biodegradation) to controlled lifetimes in plastic materials will be presented in the following section.

3.3 Available Techniques for Rendering Polyolefins and Nylons Photodegradable or Biodegradable

The techniques discussed below have been selected on the basis of (a) applicability to polyethylene/polypropylene and/or nylons and (b) the development beyond patent stage. The second requirement effectively selects the technologies considered viable enough for attempted commercialization or at least a feasibility study.

A. Modification of Polymer Chains (plastic resins) to Incorporate Photolabile Functional Groups

Method:

Carbonyl groups are introduced into the polymer by using a comonomer (a vinyl ketone) during polymerization. The 0.1 to 5 molar percent of such groups introduced into the plastic matrix is more than sufficient to make the material susceptible to photodegradation.

Typical Patents:

(1) US 3,753,952 (1973)
3,860,538 (1975)
J. E. Guillet

(2) BP 1,362,363 (1971)
1,430,085 (1976)
University of Toronto

The costly copolymerization has been avoided by resorting to a grafting technique. This is carried out on commercial plastic beads to obtain a highly photolabile "masterbatch". The plastic processer fabricating a product will use a few percent of the appropriate masterbatch compound along with the virgin polymer. Since the masterbatch is itself mostly virgin polymer of same chemical type and because relatively low levels of the masterbatch are used, the processing characteristics of the plastic mix remains virtually unchanged. The resultant product however will have built-in enhanced photodegradability.

Research literature indicates successful application of this general technology to achieve controlled outdoor lifetimes for a variety of thermoplastics including polystyrene, poly(vinyl chloride), polyesters, polyamides and acrylics.

Current Status:

For polyolefins and polystyrene, suitable masterbatches are currently commercially available. The technology can, therefore be directly applied to styrofoam cups, gill net floats, plastic bottles, containers, bait boxes, plastic bags and plastic packaging bands.

The use of this technology will increase the cost of plastic resins, and therefore that of the product, by a 5-10% at the present time. Large scale use of the process is expected to lower the costs.

Availability

The technology is available from ECOPLASTICS, Ltd., Toronto, CANADA. Contact Person: President: Dr. Anthony Redpath

Note:

1. A similar resin modification process using carbon monoxide/-ethylene copolymer is available with Union Carbide Company. However, this degradable resin is not generally available at this time and is about 25% more expensive than regular polyethylene.
2. Several states now require the disposable six-pack carriers (yokes) to be enhanced-degradable. The low-density polyethylene carriers marketed in these states are rendered photodegradable (outdoor life ~120 days to embrittlement) using this basic technology. HiCone Division of Illinois Tool Works currently manufacturers the controlled lifetime six-pack carriers.
3. A related patent owned by the company describes the extension of the same technique to nylons. (US 4,042,568 (1977) and BP 1,372,182 (1971) assigned to the University of Toronto, 1977).

The technique described therein is on the preparation of condensation polymers such as nylons in a manner to incorporate photolabile ketone groups into the polymer structure.
As already pointed out, nylons do not float. The density of nylons might be reduced to an extent to allow floatation by slight foaming of the nylon monofilaments. However, this is likely to impair the efficiency of the gear because of reduced strength and increased visibility of monofilaments under water.

Advantages

The mature state of development which will enable rapid transfer of the technology to plastics in marine environment is the most important advantage. In fact, with the polyolefins, only minimal developmental work will be required to determine (a) if the lifetimes of interest in fishery applications is attainable, (b) if presence of water substantially affects controlled life time; and (c) to determine economic feasibility.

B. The Use of Photosensitive Additives in the Plastic Composition

Method:

The rate and the extent of photodegradation is governed by the amount of light energy absorbed by the plastic. However, plastics do not generally absorb significantly in the UV region (in fact, pure polyolefins are not expected to absorb any UV light at all; it is the presence of additives/impurities which lead to absorption of UV-light and consequent degradation.)

Mixing in a small quantity of a suitable very highly UV-absorbing material (which can efficiently absorb and transfer the energy) into the polymer, results in increased light absorption and availability of the absorbed light energy for photodegradation. A variety of such photosensitizers are available. Depending on the type of compound used and the concentration of the additive, different rates of photodegradation are obtained.

The following classes of compounds have been particularly effective as additives to enhance photodegradability.

(i) Transition Metal Complexes

Simple salts, oximes, acetylacetanoates and dithiocarbomates of cobalt, nickel and iron, in relatively low concentrations impart enhanced photodegradability to polyolefins. The dithiocarbomates, in particular, allow some degree of control of the controlled lifetimes and is also melt-processible. Enhanced photodegradable low density polyethylene film containing ferric dibutyldithiocarbomate was marketed under trade name "Ecoten".

Typical Patents

US	4,038,227	1977
UK	1,356,107	1974
Ger	2,839,867	1978
USSR	626,101	1978
Jap	7,828,643	1978

(ii) Carbonyl Compounds

Carbonyl compounds, especially the ketones, absorb light and induce degradation of the polymers into which they are incorporated. Quinones, for instance, have been widely used in this capacity. Ketones, such as benzophenones are believed to act via a radical mechanism invariably involving hydroperoxide formation in the polymer. Therefore, these additives when used in conjunction with transition metal salts leads to even more accelerated degradation.

Typical Patents

US	4,038,227	1977
US	4,024,324	1977
Jap	7,410,945	1974
UK	1,371,043	1974

(iii) Other Compounds

A wide variety of both polymeric and non-polymeric additives have been claimed as photodegradation enhancers, in patent literature. They are too numerous to be addressed here, and are beyond the scope of this report.

Current Status:

The various additives are available as an additive package for use with various thermoplastics. Alternatively, a masterbatch based on a specific type of plastic might also be made available.

Availability

Princeton Polymer Laboratory, New Jersey, USA

Contact Person: Dr. Donald Hudgin

Advantages:

The same advantages mentioned in connection with the section A, above, is applicable to this technology as well. The degree of acceleration of the photodegradation achieved, as well as that of control of useful life, is about the same as for (A) above. The manufacturer claims the increase in cost of the resin containing additive to be about 3-4%.

Note: (1) The use of a small molecule additive to promote photooxidation may have a limitation in the specific case of fishing gear. Lost gear is exposed to water for long periods of time. The additive may leach out of the plastic in substantial amounts to prematurely arrest the degradation. Furthermore, the toxicity of any materials which may leach out is also of some concern. However, no experimental data is available on the question of the leachability of these materials in water.

C. Use of Starch in Plastic to Promote Biodegradability in the Absence of Light

Two types of starch-plastic compositions have been patented.

Method 1

Starch granules suitably surface treated to make them compatible with the hydrophobic plastics, is used as the additive. The mechanism by which the acceleration in biodegradation is achieved is not completely understood. However, the phenomenon has been demonstrated in the laboratory and carbon-14 experiments show that in addition to the starch, the plastic material too undergoes faster deterioration. Supplementary additives are used along with starch granules for better control of lifetimes.

Patent:

BP 1,487,050

1,485,833

French 2,184,657 Coloroll Ltd.

Current Status:

The appropriately surface treated corn-starch materials are available for incorporation in plastics, particularly those used for extrusion blow-molding (grocery bag manufacture). (See Appendix I)

However, the use of the additive increases the cost of the product by about 5-7%. At least in the US and Canada, the additive has not caught on perhaps because the consumer is not willing to pay a premium for induced biodegradability in throw-away items. The additive is used in a very limited market in England.

Availability

St. Lawrences Starch Company

Mississauga, Ontario, CANADA

Contact Person: Mr. Ian Gray

Dr. Graham Chapman

Method 2

This method requires prior gelatinization of the starch to obtain a smooth viscous dispersion of the starch in water. The starch-dispersion is mixed with an ethylene-acrylic acid copolymer and the excess acidity is neutralized with ammonia. The resulting plastic resin can be either mixed with polyethylene or directly processed into plastic films.

Patents: US 4,133,784 1980

US 4,337,81 1982

Current Status

The technology has been patented and the patent assigned to the US Department of Agriculture. The invention is owned by the US Government and has not as yet been commericalized. The amount of field data available is rather limited. No data on fresh water/marine environments exists.

Availability

US Department of Agriculture

Hyattsville, Maryland 20782

Contact Person: Felix H. Otey

Advantages

The primary advantage is that this technology for introducing biodegradability does not rely on exposure to light. This is particularly appealing as it would be applicable to nylon gill nets and also trawl webbing. Some small degree of opacity may result from incorporation of the additive in nylon monofilaments. Whether the extent of such opacity will interfere with fishing efficiency or if mechanical properties of the monofilament will change due to presence of starch granules, is not known at the present time.

Disadvantages:

The technology has not been demonstrated for nylons or even for monofilaments of polyolefins. While the process was shown to occur under soil, its effectiveness is sea-water has yet to be demonstrated. However, on the basis of technical considerations the biodegradative activity might be expected in sea water, as well.

D. Use of Various Biodegradable Plastics as Blends with either Nylon or Polyolefin to Obtain a Biodegradable Gear

Method:

Several biodegradable plastic materials have been developed in the United States and in Europe. These show excellent controlled-life characteristics in various biomedical applications. It is very likely that these materials blended with plastics of interest will perform similarly in a marine environment.

Provided that these polymers are blendable with nylon and/or polyolefins and if such blending does not seriously affect the critical properties of the material (i.e. those properties of interest in fishing gear applications), such blends might be used for fishing gear construction. The biodegradable component in such gear, might be adjusted in a manner to obtain controlled lifetime on exposure to water.

Availability:

(i) Biodegradable poly(alkylene carbonates)

Air Products

Allentown, Pennsylvania (USA)

Contact: Mr. J. J. Weber

(ii) Biodegradable poly(valeric acid)

Marlborough Company

Cleveland, England

Current Status:

Several recently developed polymers are claimed to be totally biodegradable. On exposure to body fluids (and other environments) they rapidly biodegrade to form non-toxic degradation products. These are not at the present time available in commercial quantities.

Advantages:

Assuming that blending a biodegradable polymer with either nylon or polyolefin materials will result in a controlled life-time plastic, the approach is an attractive one. The technology of polymer blends have been well studied. Such blending will often not alter processing requirements and will not need pre-treatment of the material (as in the case of the starch additive).

Disadvantages:

With regard to fishing gear applications, the approach remains essentially unproven. A significant research effort is needed to demonstrate the validity of the concept as well as to extend it to the plastic materials of interest.

3.4 Novel Approaches to Controlled Biodegradation of Abandoned Fishing Gear

Current modes of gear use and the types of materials used in gear manufacture suggest the following minimum requirements for a degradable gear; (a) act in water in the absence of light; and (b) be non-toxic and inexpensive.

Two approaches which are consistent with the above criteria, but not developed as yet, were identified during the study.

(i) Utilization of Adhesives for Gear Manufacture

Adhesives represent an advanced, rapidly exploited segment of the plastics industry. High performance adhesives are available for a variety of applications and can be formulated to achieve specific key characteristics.

If fishing gear can, in fact, be manufactured using adhesive joints in place of the conventional knotted joints, the product integrity is unlikely to suffer. Furthermore, the adhesive component might be so designed to undergo controlled biodegradation on prolonged exposure to water.

The approach is particularly promising for crab-pots, where the pot construction can be of reinforced plastic and adhesives. Degradation of the adhesive would ensure the pot to be non-functional on being lost or abandoned.

The approach assumes that adhesives can be so compounded to have a controlled lifetime in water.

(ii) The Use of Nutrient Materials in the Polymer Matrix

Certain classes of low molecular weight compounds act as nutrient sources for microflora/microfauna. Such materials might be used as an additive in the plastic. On prolonged exposure outdoors in water, these diffuse out to the surface of polymer possibly creating a local high concentration of the compound in the vicinity of lost gear. Consequently, it is hoped, that an accelerated growth of marine organisms might be promoted on the gear surface. The weight of growing colonies will sink the net to the bottom, immobilizing it. An accelerated biodegradation would then follow.

Observations on underwater gill nets by Carr (1984) showed some growth of bryazoans (anemone metridium species and ascidian Boltenia sp) and also some algal species on the nets. The proposal here is to accelerate what appears to be a natural phenomenon by encouraging a wider range of plant and animal life to grow on the netting.

NOTE: Neither of these ideas have been tested or experimentally illustrated. It is not claimed that they are applicable to fishing gear.

4.0 Degradable Gear: An Assessment

4.1 Characteristics of Preferred Types of Degradable Gear

From a fisheries technology point of view, the various approaches and techniques for rendering fishing gear degradable, must conform to several key requirements. These are as follows:

1. The altered gear (or plastic material) must not introduce toxic materials into the marine environment. (Natural degradation of polymers does not add any toxic compounds into marine environment.)
2. The process must not substantially alter the physical and mechanical properties of the product, in a manner to affect its usefulness in the fishing operation.
3. The technique should not demand extensive changes in current gear-manufacturing technology. (This will adversely affect the cost of the treated gear.)
4. It should be possible to obtain closely controlled lifetimes using the approach.
5. The approach must be economical.

The various techniques discussed in the previous sections are shown in Table 4.1 along with their degree of conformity to above requirements. Also indicated are the different plastics products which might be rendered degradable by the various techniques.

In principle, biodeterioration should occur in any suitably treated (additive containing) plastic. The table therefore identifies it as a general approach suited for all plastics. However, the floating debris (of Groups 1 and 3) of mainly the polyolefin and polystyrene, often end up on dry sandy beaches where little or no biodegradation can occur. The intact piece of plastic debris may subsequently return to sea due to

Table 4.1 Relative Merits of Various Approaches to Degradable Fishing Gear

	(a) Toxicity	(b) Properties	(c) Manufacture	(d) Lifetime	(e) Economy	(f) Proven	Products
A. Photodegradation (Approach A)							
(i) Resin modification	No	Y	No	Yes	Yes	Yes	floats, packaging bands, bait boxes, plastic bags, cups, bottles, etc. and trawl webbing (Group 1 and 3)*
(ii) Using addivites	No	Y	No	Yes	Yes	Yes	
B. Biodegradation (Approach B)							
(i) Starch additive	No	y	No	Y	Yes	Yes	All of above and gill net material (All 3 groups)*
(ii) Blending degradable polymer	No	Y	No	Y	U	No	
C. Novel Approaches							
(i) Adhesive based gear	No	Y	Yes	Y	U	No	All net materials
(ii) Gear treated to promote growth of marine organisms	No	Y	No	Y	Yes	No	All plastic material

KEY

Y - (Likely, but <u>not</u> demonstrated)
U - (Unknown at this time)

(a) Is the system likely to yield toxic materials?
(b) Will the process leave the plastic properties unaltered?
(c) Will the process require substantial changes in gear manufacture?
(d) Does the process give closely controlled lifetimes?
(e) Is the process economical?
(f) Has the principle involved been experimentally demonstrated?
* Groups refer to those of litter as classified in the Introduction.

either wind or tidal action. For such products, a photodegradation route is probably preferable.

Alternatively, for nylon-based gear (which sinks in water), biodegradation is clearly the preferred pathway.

In the case of non-gear products which pose a threat to marine life (such as plastics packaging bands, styrofoam articles, etc.) photodegradation is probably the more convenient route to take, as the technology is already proven and mature. Using biodegradation as a means of obtaining controlled lifetimes in such material would mean a significant research effort (and therefore a lag time before a usable product is available.)

It is clear that the preferred route to degradability is different for different types of plastic materials. The table identifies two technologies each for the first-two approaches (photodegradation and biodegradation). Determining the more appropriate technology within a given approach for a specific product is a difficult task. None of the technologies have been applied to fishing gear nor have they been demonstrated under marine environmental conditions. This lack of experimental data prevents clear identification of preferred technologies at the present time.

4.2 Fishing Efficiency of the Degradable Gear

Since the physical properties (such as color density, etc.) and mechanical properties (strength, extensibility, etc.) of the treated plastic are virtually the same as that of the untreated plastic, fishing efficiency is not expected to be affected by the treatment process.

In the case of biodegradation technologies there is a concern that the inclusion of starch granules (or biodegradable polymer) may render the plastic filaments slightly less transparent in water. This may have an affect on the catchability of gill nets depending upon the degree of opacity imparted. (It has not been conclusively shown that monofilament transparency is an important factor in determining fishing effectiveness of a gill net.) The validity of the concern cannot be determined without resorting to an experimental study.

Controlled lifetime gear is designed to lose its mechanical integrity on extended exposure to the marine environment. The question of how closely the lifetime of gear can be controlled by these technologies, remains unanswered at the present time. If such control is not possible a danger of premature gear failure would exist. On the basis of available data, both the approaches (photodegradation and biodegradation) seem to be able to yield controlled lifetime products. For instance, in the case of floating (Group 1) debris, it is clear that these technologies can effectively control the problem.

In the case of fishing gear, the utility of the technologies depend upon their being able to provide, not only close control of the lifetime, but also absolute lifetimes of the time scale dictated by fishing industry considerations. Unlike in the case of plastic debris (and litter), the objective is not to use the item once and to ensure rapid deterioration on discarding it. Various technologies developed to address the plastic litter problem, may need some modification before successful application in the marine environment. This again is a concern which must essentially remain unanswered until the relevant experiments are carried out.

5.0 Conclusions and Recommendations

5.1 Main Conclusion

1. The various plastics debris which pose a threat to marine life can in most instances be rendered relatively less hazardous using both controlled photodegradable and controlled biodegradable plastics.
2. Currently available technologies for rendering plastics photodegradable can be immediately utilized with minimal developmental effort, to neutralize the hazard posed by some of the disposable items made of polyethylene or polypropylene. These include packaging bands, packing ropes, cups, containers, etc. used at or near sea.
3. Gill net floats, a major component of debris, can be similarly treated to limit their lifetime outdoors, at a level which allows them to last their current useful lifetimes, but ensure rapid deterioration on further exposure.
4. Gill nets currently used in various fisheries are made of nylon, with a definite trend towards the lighter monofilament gear. Being denser than sea water, nylon debris do not float, and are hence not susceptible to photodegradation at sea. However, viable technologies for biodegradation might be employed.

   Seasonal, short life-time monofilament gear such as Herring gill nets (~ 1 year) and salmon gill nets (~ 3 years) can be rendered biodegradable using controlled life times in excess of current periods of utility.

   Available data suggests a high degree of control of lifetime can be achieved with techniques for rendering nylons and other plastics biodegradable. Regular, nylon filaments do not appreciably degrade in sea water and consequently last very long periods of time as debris. Therefore any improvement in the way of limiting their lifetime will have a substantial impact. (A moderate research effort is anticipated.)

5. The same is generally true of crab-pot webbing.

6. Trawl web, a significant component of debris, is susceptible to both photo and biodegradation at sea. However, this gear poses a special problem.

   In both bottom and mid-water trawling (where polypropylene webbing is used), the gear is subjected to uneven abrasive wear and tear. Consequently, the gear web is replaced in sections as needed. Invariably, the gear in use is composed of several sections of webbing, of different age. There is no single service life for entire gear. Identification of maximum service life is a prerequisite for application of controlled biodegradation techniques.

   However, two approaches might be considered:

   (a) The controlled life-time might be selected on the basis of least replaced section of the gear. This may lead to rather long life-times for lost sections of webbing, but yet constitute a very significant reduction in the hazards posed by such debris.

   (b) Only the most replaced sections of gear (probably the under side "belly") might be required to be made of controlled life-time webbing. This may lead to routine replacement of these sections of gear with fresh webbing even in instances where (through careful use) the webbing has not been significantly damaged.

7. Several sources for provision of the technologies required for above-mentioned improvements of gear has been identified. All

sources listed below do not, at the present time, have all the experimental data needed to enable selection of the best among competing techniques.

Controlled Photodegradability

Princeton Polymer Laboratory (USA)

Ecoplastics Ltd (Canada)

Union Carbide Corporation (USA)

Controlled Biodegradation

US Department of Agriculture

St. Lawrences Starch Company (Canada)

Marl Borough Biopolymers Ltd (England)

While all of these techniques are laboratory demonstrated and patent protected, none has been shown to be applicable under marine conditions nor demonstrated to induce controlled lifetimes of the time scale required for the present purposes.

5.2 Recommendations

The information collected suggests that any future research effort, at least in the early stages, should be multi-directed. The effort may include the following:

1. Developmental work on transferring controlled photodegradation technology to plastic packing bands, other polyolefin articles, and polystyrene floats.
2. Experimental demonstration of controlled photodegradation on relevant plastic compositions under marine environmental conditions.
3. Laboratory demonstration of effectiveness of various biodegradation technologies.
4. Research aimed at establishing controlled lifetimes in monofilament nylon and/or polyolefin extruded fibers.

5. Studies on synergism in photo and biodegradation of relevant nylons and polyolefins.
6. Characterization of the bio/photodegraded plastic residue to determine its impact on marine environment.
7. Investigation of novel methods of imparting biodegradability in nylon monofilament fishing gear.
8. Effects of ingestion of partially/fully degraded plastics in selected marine species.
9. Fabrication and preliminary testing of improved gear. This is to ensure that the improvement does not result in immediate apparent deterioration of fishing effectiveness.
10. Coordinate research efforts with both non-US researches and international bodies which might have concerns about the problem.

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APPENDIX I

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Biodegradation

Defined here as the breakdown (ultimately to small molecules) of the polymer by the action of microorganisms such as bacteria and fungi.

Typically, biodegradation occurs when the material is in contact with an environment where microorganisms might be present. Such environments include soil, fresh water and the sea.

Mechanism

The invention consists of adding a two-component additive to the plastic. First, are starch particles, appropriately treated to render them sufficiently hydrophobic for inclusion into polymer matrix.

Microrganisms readily attack the starch grains, initially at the surface layers, and then in the bulk of the polymer. This renders the matrix weak due to formation of weak areas (or voids) within the plastic.

The second component is a polyunsaturated fatty acid/heavy metal salt mix. The ester readily autooxidizes yielding hydroperoxides according to well known reaction sequence. Heavy metal salt acts as peroxide decomposition catalysts generating free radicals which promote oxidation of polymer. Oxygen containing polymer chains which are formed due to this process are more amenable to attack by microogranisms than the starting polymer.

The net result is the weakening of bulk polymer due to starch degradation as well as the biodegradation of the oxidized polymer leading to rapid decrease in average molecular weight of the chains.

Starch Grain Pretreatment

Corn starch, specially treated, is currently used in the preparation of masterbatch. Other starches, such as rice starch, may also be possibly used. The diagram below shows the main steps in the preparation of the starch.

Corn Starch
↓
Weighing and Cleaning
↓
Degerminating
↓
Grinding
↓
Fiber ← Washing Screens
↓
Gluten ← Centrifuge
↓
Finished Starch Milk
↓
Special Starch ← Regular Starch → to Glucose Refinery
Catalyst → ← Surface Modification
↓
pH Adjust ↓
↓
ECOSTAR

Rate of Degradation

The rate of degradation of a polymer by microorganisms is generally dependent upon several factors.

(a) Availability of moisture

(b) Availability of microorganisms

(c) Temperature

(d) pH value of medium

(e) Type of polymer and compound additives used

(f) Surface area exposed to environment

The various environments are not adequately characterized. Yet the data shows that, at least in this product, substantial decreases in mechanical properties are possible on short term exposure.