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The Ecological Impact of Shrimp Trawling In Tropical Waters

A Report prepared for the

International Collective In Support Of Fishworkers

By

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I. An overview of shrimp fisheries

A. Warm water sources

Large fisheries for warm water, "penaeid", shrimp occur in the waters off Indonesia, Thailand, India and in the Gulf of Mexico (Gulland and Rothschild, 1984). Warm water shrimp dominate the world market. Penaeid shrimps compose half the world's shrimp catch which amounts to 2.4 million mt worth $2 billionUS. They are classified as whites, pinks, browns, and tigers. The standard product, green headless, is uncooked and headless. White shrimp are from wild capture fisheries off Mexico and India as well as from waters of the South Atlantic and Gulf of Mexico. They are farmed in Mexico, Ecuador, and China. Whites are known for their firm texture, mild taste, and light pink color when cooked. Tiger shrimp are primarily cultured in Asia. They have a softer texture and higher water content then other warm-water shrimp. Pink shrimp are noted for their sweet flavor.

B. Cold water sources

The cold water, or Northern shrimp, are produced off the coasts of Norway, Greenland, Iceland, and the Northern part of the USA. They are sometimes referred to as salad shrimp in the marketplace.

C. Aquaculture

The shrimp aquaculture industry is rapidly changing, and highly competitive, making it very difficult to predict and track. The major species under culture is tiger shrimp, *Penaeus monodon*, representing about 58% of production primarily from Asia. The Latin American countries produce mostly white shrimp, *P. vananamei*, which represents 22% of world farm production. World production of cultured shrimp is around 700,000 metric tons. The farm-gate value of cultured shrimp is over six billion US dollars and represents about 25% of the world's shrimp supply. The 1996 production figures for major producing countries are Thailand (160,000 mt), Ecuador (120,000 mt), Indonesia (90,000 mt), China (80,000 mt), India (70,000 mt), Vietnam (30,000 mt), Bangladesh (35,000 mt) and Mexico (12,000 mt). China and Taiwan have produced large amounts of shrimp (200,000 mt in 1972) but have suffered major crop failures in recent years. Projections are for farm production levels of 1.6 million metric tons annually by 2005 which would be about 60% of the world's supply.

The shrimp culture industry is beset by two major problems; the provision of broodstock and environmental/disease issues. Female shrimp are difficult to spawn in captivity thus the harvesting pressure on wild caught mature females for spawn is intense. Mature females have been selling for over $100US in Southeast Asia in 1997. A significant amount of research is underway worldwide to find economically viable ways to maintain a brood stock in captivity.

The relationship between environmental problems and disease in pond culture is not fully understood. Production in ponds used in intensive culture gradually deteriorates over time even without disease outbreaks. The use of antibiodics to treat shrimp ponds and the resultant emergence of multi-resistent strains of bacteria has raised serious concerns. White Spot Syndrome Virus (WSSV) disease, which has no known cure, will require shrimp farmers to clean-up their operations in order to remain viable. Taura Syndrome Virus (TSV) is becoming a major problem in Latin America and also will reguire pond sterilization. The spread of WSSV from Asia into the USA has raised concerns that this virus could spread into wild shrimp stocks as well. The environmental concerns of coastal waters contamination and contamination through soil leaching will force farms to be less intensive and more self-contained. The impacts of the recent court rulings in India on coastal shrimp farming are impossible to predict.

The issue of new species introduction is also gathering attention. The trend will be for countries to identify native shrimp species that are amenable to culture.

The socio-economic make-up of the shrimp culture industry in Southeast Asia is also not fully identified. While the wealthy investor owned companies are highly visible there is a large number of individual owner-operators. Many of these people were fishermen who have sold their vessels to farm shrimp on small parcels of land. The World Shrimp Farming 1996 annual publication estimates over 110,000 farms, mostly in Asia. Many are organized in cooperatives where the farmer owns the land and the sponsoring organization provides the seedstock, feed, technical support, and marketing.

D. World markets

There are two types of shrimp from a marketing standpoint; warm water and cold water. Shrimp is one of the most popular of seafoods served outside of the home in developed countries. In the USA alone, 340 million kilos were consumed in 1995; over 15% of USA seafood consumption. The supply of shrimp to the USA market comes from over 85 countries; half of the supply being farmed product. Thailand, Ecuador, Mexico, India, and China provide 75% of these imports to the USA.

II. Harvesting methods

Shrimp harvesting is commonly divided into two categories; industrial fishing and small-scale or artisanal fishing. The first category usually covers offshore fisheries on adult stocks conducted by bottom trawls. The latter category covers coastal fishing operations most often on juveniles. This categorization is not always well defined thus this section will present harvesting operations in terms of the gear used to catch shrimp.

A. Trawling

Trawling is a fishing method in which a vessel tows a net referred to as trawl gear or just "gear". The net is basically cone shaped. The large mouth of the cone is the forward end and is widened by netting extensions called wings. The aftmost narrow end is called the cod end and is where the catch accumulates. Vessels that tow the gear are referred to as trawlers and when towing bottom trawls are commonly called draggers. The net can be set and hauled from the side (side trawler) or the stern (stern trawler). Nets can be towed by one or two vessels; the latter method is called pair trawling. When a single vessel tows two trawls, one off of each side, it is referred to as being double rigged; three trawls and its triple rigged. Most shrimp vessels are double rigged, one net from each side, and tow a much smaller try net off the stern. Double rigs can sweep the same area with less drag thus are more efficient. Trawling was introduced into the Gulf of Mexico shrimp fishery in 1913; before that haul seines were used inshore. Double rigs began in the Gulf of Mexico shrimp fishery off Texas in 1955. Double rigged twin trawls entered the fishery in 1972 (Bullis and Floyd, 1972).

In single vessel otter trawling the net is controlled (set, towed, and hauled) by either one or two towing wires (warps). A single warp is normally used with very small nets, multiple net rigs (typically shrimp trawlers), or in very deep water. The single warp splits into two, each then attaching to a separate otter board (door). In the case of dual warps, each wire is attached directly to a door. The doors are used to spread open the mouth of the trawl net. The doors are either directly attached to the net by bridles or separated by ground gear (legs and ground cable; sweeplines) that effectively widen the area swept by the net.The netting of the gear consists of panels, some of which are the wings, square, belly, extension, and cod end. The forward, lower, ends of the wings and belly are attached to a footrope, or sweep, that can range from a simple heavy rope, wire, or chain to a complex rig of heavy rollers. On mud bottom, shrimp trawls are sometimes equipped with light rollers, such as holed floats, to keep the sweep from digging in too deep.

In pair trawling, each of the two vessels is attached to one of the warps thus keeping the net open without the need for doors. Pair trawling allows two vessels to tow a larger net and sweep a greater area than if each vessel outfitted with an individual trawl with doors. In addition, in shallow water a single vessel's screw noise may chase the shrimp away from the front of the trawl but paired vessels may chase the shrimp into the trawl.

Another method of trawling that is rapidly winning favor in the shrimp trawling industry is known as twin trawling. A twin trawl is actually two nets that are attached to each other at one wing end and towed off the stern. The rig can be towed with the conventional two wire system attached to the outer wing ends where the doors are located or with an additional third, or center wire, to the point of common attachment. This rig allows a vessel either to save significant fuel or increase the swept area.

There are low opening trawls, for shrimp and flatfish, and high opening trawls, for semi-demersal or pelagic species. Trawls are also described as having two or four seams; the latter having side panels usually to gain more opening height. Trawls must be designed with target species behavior and the trawler parameters as key design considerations. For example, high profile trawls are important for good catch rates of white shrimp, *Penaeus setiferus*, but are not needed for brown shrimp, *Penaeus aztecus* (Harrington, 1992).

The size of the towing vessel and the trawl can play an important role in bycatch. Thorsteinsson (1992) reported that before 1967 there was little fish bycatch in Iceland's inshore shrimp fishery because the fish were able to swim out of the small trawls. However, with the discovery of offshore shrimp grounds, and the introduction of more powerful vessels with larger trawls, bycatch became a problem. An attempt to solve the problem by using bobbins on the footrope to allow small fish to escape underneath backfired when it resulted in vessels fishing on harder bottom where small fish were more common.

Research is underway in the USA Gulf of Mexico shrimp fishery to cut the costs of shrimp trawling. The focus is on cutting fuel costs by replacing heavy nylon twine with knotless polyethylene netting. The reduced drag of the netting decreases the size of the trawl doors required thus further reducing drag. This reduced drag, coupled with experiments with Icelandic Poly Ice trawl doors, indicate that shrimp trawling may eventually occur at higher speeds.

Beam Trawls

The beam trawl is a relatively simple piece of bottom towed fishing gear primarily consisting of a metal or wood beam holding open horizontally the mouth of an attached net. The beam is towed by wires called bridles which usually join together at the towing wire or warp. The beam rides on steel shoes (beam heads, skids, runners) mounted at each end. The attached net has a headrope fixed to the top of the beam and a groundrope (footrope, leadline) fixed at each end to the shoes. The net tapers back to a cod end where the catch is collected. A typical large beam may be 10 meters long and ride about one meter above the seabed on its skids.

The actual fishing activity takes place at the groundrope which arcs back from the shoes and is usually preceded by a series of tickler chains. These chains can be very heavy as their purpose is to dig into the bottom to scare up flatfish and shrimp. Some Dutch beam trawlers, fishing for sole, are rigged with 15 chains with a total weight of 2000 kg. The gear of a 1900 HP Dutch beam trawler, representative of her class, can weigh 7000 kg (net material, 1200 kg; trawl heads and beams, 3800 kg; chains and ticklers, 2000 kg). This creates a large amount of drag requiring relatively substantial horsepower for towing. On the other hand, since the gear can also be towed at very slow speeds, it can be more fuel efficient under certain fishing conditions than an otter trawl (At very slow speeds the otter boards or "doors" fall down.). Beam trawls are common in the sole fishery out of Belgium and Holland as the target species is not as vulnerable to lighter gears. This fishery has opted for high speed and heavy gear towed by powerful engines.

The advantages of beam trawling, from the fisherman's perspective, are based on the fact that the net mouth opening remains fixed regardless of warp (towing wire) length (scope), vessel speed, cross-tides, course changes, substrate type, or number of heavy tickler chains. The main disadvantage is that the gear can not sweep as large an area (or volume of water) per unit time as an otter trawl for a given horsepower and is physically limited in size. Beam trawlers can be rigged with outriggers off of each side (double rigging) so that they can tow up to four trawls at once, though this is not common. Another disadvantage is the gear can load up with non-target benthic organisms and substrate thus adding sorting time and reducing market quality of the catch. However, in a beam trawl fishery directed at shrimp or crabs, the fish bycatch in most cases would be significantly lower than in an otter trawl. Boddeke (1992) advocates the use of low beam trawls with Dutch type separators in penaeid shrimp fisheries because of the reduced bycatch and a 40% energy savings compared to otter trawls. This gear is fished without tickler chains but with rollers attached to the groundrope (Berghahn, 1992).

B. Trapping

Traps

Traps, or pots, are self contained units used to catch fish or crustaceans (eg, not the fixed weir-type traps found in areas along the coastline). These traps are usually in the form of a cage that have one or more openings or entrances designed in such a manner as to prevent the target animal from escaping. Traps are normally baited and set on the bottom singly or in strings (trawls) marked on the surface by buoys. Common construction materials include wood, metal and plastic.

The amount of time a trap spends in the water fishing is called the "soak-time". Some traps are designed to be hauled very frequently (every 15 minutes) while others are left in the water for many days before being hauled. Species composition of the retained catch can change with soak-time.

Trapping has been proposed as an alternative to shrimp trawling as it would improve catch quality, minimize habitat degradation, and reduce fuel consumption (Buckworth and Cann, 1992). Baited traps do catch shrimp ; the issue is wether or not they can do so at an economically feasible level. Buckworth and Cann modeled the potential economics of a shrimp trap fishery in Australia's northern prawn fishery and found that high shrimp prices were needed for such a fishery to be viable.

Shrimp traps have been in use in the Gulf of Maine for over twenty years (Schick, 1992) primarily by boats rigged for lobster trapping. The rectangular traps are made of vinyl coated steel wire and have top entrances. The bait is usually herring or mackerel and bait placement relative to the trap entrance is critical. The traps have very little bycatch as a result of the narrow entrance opening. The entrance is sized to keep crabs out of the gear as they would eat the shrimp if allowed into the trap. In the Gulf of Maine, trapping has not spread significantly due to gear conflict with mobile fishing operations and that it can't compete economically with trawling. The higher quality and larger trap caught shrimp can sell with a 25% premium over trawled shrimp but this still is apparently not enough of an inducement.

In 1987, experiments with plastic shrimp traps began in Indonesia (Barus, 1988). Trawling for shrimp had been banned in Indonesia since 1980 thus shrimp fishing was conducted with trammel and gill nets. Research was undertaken to design a trap for the inshore fishermen made of readily available materials, ie, common plastic baskets. Fishing operations consisted of ten baited traps set attached to a single longline. The traps caught few shrimp and at times had high catches of fish and crabs.

If it can be established that trapping offers broader environmental and/or social advantages to the resource and industry than trawling, then government intervention could change the situation by imposing restrictions on trawling (taxes, closed areas, gear limitations) and/or by giving incentives to trappers (earlier access to stocks, protected areas). However, politically this is very difficult to accomplish when most fishermen are vested in the offending gear type, in this case trawling, unless the offense can be established beyond question. What is more likely to happen is that trawling may be banned in an area in order to protect an over-exploited finfish stock thus allowing shrimp trappers access to those grounds.

C. Other gears

There are many gears that have been used in shrimp fisheries around the world in addition to those described in the previous sections. In general they can be grouped as follows; fixed nets (tidal traps), drift nets, seine nets, cast nets, and scoop/push nets. Silas et al (1984) describe gears used in India by using this categorization.

Tidal traps are an age old method for capturing shrimp. The traps are placed in channels that adolescent shrimp pass through on their migration from the nursery areas out to sea. The traps can be harvested by the use of dip nets. Chinese barriers are a type of trap commonly used to catch small shrimp for aquaculture stocking. They consist of screened guides that lead the shrimp into catch chambers.

Beach seines for shrimp vary in size from ones that require only a few men to ones that require over 60 men to operate. The nets can be set by foot in shallow areas or by small boats but in all cases the ends are attached to ropes that are pulled up onto the beach. The mesh sizes in the seines are usually small and the shrimp caught are also usually small. Some researchers consider this gear type harmful to shrimp and finfish fisheries because of the retention of juvenile shrimp and fish (Vendeville, 1990).

Cast nets can range from a single simple throw net to a number of nets tied together and towed by a vessel either by drfting or power. The latter method, called the suripera in Mexico, was shown to be about three times more efficient than the simple cast net with half the bycatch (Chavez, 1992). Off the Southeast coast of the USA, white shrimp (*Penaeus setiferus*) are harvested using bait with cast nets (Whitaker et al, 1992). This is a recreational fishery, conducted at night. Fishermen place a marking pole in the shallow water (<1.8 m) and chum with a bait made of mud and fish meal. When the shrimp are attracted, usually 15 to 30 minutes, the casts are made. The monofilament nets have radii from 1.5 to 1.8 m and mesh sizes from 9.5 to 12.7 mm on average. The larger mesh sizes are more size selective for larger shrimp. When fishing is good the catch limit of about 50 liters of whole shrimp can be taken in under an hour. The boats used range from 3 to 6 meters in length and are powered by outboards. The fish bycatch is low, even lower than traditional casting methods and seining, and those caught are usually returned to the sea alive.

In the Pohai Sea chinese shrimp (*Penaeus orientalis*) fishery, drift nets are used (trawling for shrimp was banned) (Changchen et al, 1992). The fishery is conducted from vessels under 130 hp. The nets, which originated as fixed or set gill nets, are commonly 62 meters long (1500 meshes of 60 mm) and 5.2 meters deep (120 meshes) with a vertical and horizontal hanging ratio of 0.7. The nets are set perpendicular to light currents and hauled fast to reduce shrimp loss. To encourage shrimp drift netting over trawling the government opened the shrimp season ten days earlier for the drifters. Virtually all boats shifted to drift nets making it easy to ban trawling thus eliminating a fish bycatch problem that existed. Government intervention, in the form of allowing an earlier drift net opening, was needed since a drift net operation only caught about 25% of what a pair of trawling vessels caught. However, four drift net vessels cost less than a pair of trawlers thus while economic efficiency and employment grew, stock overfishing also increased. Stock enhancement efforts were started and have been highly successful in the Northern Yellow Sea but not the Pohai Sea (Ibid).

Butterfly and skimmer nets are commonly used in the inshore shrimp fishery of the Gulf of Mexico. The newer skimmer net is designed to fish the entire water column while the older butterfly net only fishes near the surface. The butterfly net (wing net) was introduced in the 1950's and consists of a rigid frame with net attached in such a manner that the cod end can be dumped without interrupting fishing (Perret and Bowman, 1992). The nightime fishing operations are conducted in tidal currents with the vessel stationary or with the nets being pushed ahead. The nets are also fished from fixed platforms. The butterfly net was followed in the 1980's by the chopsticks trawl; a net held open by two sticks that rode on a large skid. The trawl was banned but lead to the development of the skimmer net. The skimmer net consists of an L-shaped frame; one end attached to the vessel and the other end riding on a skid on the sea floor. Most vessels fish two skimmer nets, one on each side. Compared to otter trawls, butterfly and skimmer nets have lower bycatch rates and release the discards in better condition. The skimmer net is easier to manuever than an otter trawl and is very efficient for white shrimp since it spreads from seafloor to sea surface (3.6 m depth maximum limit set by law). Some fishermen consider the gear too efficient and a threat to future production (Hein and Meier, 1995).

III. Bycatch

There is not a simple or universally agreed upon definition of bycatch. Bycatch, as defined here, is a combination of incidental take of non-target species that are utilized, and of all species that are discarded for whatever reasons. The animal needs to be placed on deck to be counted as bycatch. If it falls out of the gear before it hits the rail, it falls into the category called "dropout", another form of incidental fishing mortality.

There are a number of key points that must be kept in mind. Not all bycatch that is discarded is dead. Some portion survives and there are usually actions that can be taken by the fisherman to increase the percentage of survival. There is also the possibility that a clean or selective fishery that only removes certain species or size animals may have long-term ecological consequences. Thus the feeling that bycatch mortality (landed or discarded) is bad, selectivity is good, may not be correct in many cases.

Ecosystems are complex, and while there might be simple solutions to their management, these solutions have not been easy to identify due to our lack of understanding of ecological relationships. Over-emphasizing bycatch issues compared to other harvesting considerations might neglect ecosystem relationships and risk causing even greater problems. Resource managers may want high bycatch mortality, high but albeit sustainable, in certain cases to maximize the values generated by a particular ecosystem. For example, a fishery harvests a fish that is the major predator on a non-commercial crab resource. The crab population thus explodes and preys upon a valuable shellfish resource that collapses under the heavy crab/human predation. To maximize the values from this ecosystem managers may want the shellfish harvesting gear to inflict non-catch mortality on the crab bycatch. The analogy would be farmers weeding their fields. The solution to fish bycatch problems in some tropical shrimp trawl fisheries has been to find commercial markets for the fish. There is also the situation where gear A has no bycatch but uses ten times more fuel per unit of target catch than gear B that has some bycatch.

In addition, bycatch laws have the potential to destroy the small multi-species coastal fisheries by regulatory burden. Accurate accounting of bycatch that is discarded will have to be verified by regulatory authorities. Since some of the bycatch that occurs at sea is discarded, and commonly not reported by the fisherman, a frequently used solution for accurate verification is the use of onboard observers. This can be very costly to the party paying for the observer; either the government or the vessel owner. Small coastal vessels often can not afford the cost of observers and in some cases do not have the room to carry them.

Commercial Bycatch

Commercial bycatch consists of species that are commonly marketed. Commercial bycatch can be considered another aspect of fishing mortality, a natural cost of doing business, that must be factored into each fishing equation. It can be size and/or species related. For example, when a vessel targets shrimp on certain grounds there may be an incidental catch consisting of finfish. This incidental bycatch is not necessarily unwanted, depending on the condition of the stock, if it is of legal size and can be sold. However, it is not too difficult to define some scenarios were it becomes a problem. The first scenario would be if there was significant discarding of undersized fish and associated high mortality. Discarded bycatch may survive, although for some species, especially sessile ones, displacement is a concern. The simple solution to bycatch that is ultimately discarded, is not to bring it up in the first place. A second scenario is that the fish stocks might be so overfished or endangered as to require a cessation of all fisheries catching that stock. The shrimp vessel's bycatch of fish might exceed a bycatch quota, thus closing the fishery on a healthy shrimp stock.

Bycatch is the regulatory phenomena and gear selectivity is the technical issue. For example, if the minimum legal shrimp size is raised, the bycatch is changed (discarding of undersized shrimp increases). If, however, the mesh size is increased, the size selectivity of the trawl is changed. It is very important to keep these two concepts separate because today's catch might be tomorrow's bycatch without any change in gear selectivity. Whether a species is target or bycatch can also change as new fisheries are developed or new markets created. Bycatch is often created by managers allocating fishery resources. It is obviously shaped by politics; one interest group against another. Bycatch allocation is a very difficult decision process in fisheries managed by quotas.

Non-Commercial Bycatch

Non-commercial bycatch consists of those species not commonly marketed. In the past it was commonly referred to as “trash” and consisted of benthic organisms as well as unmarketable fish species. More recently concerns for endangered and threatened species have added a new dimension to the term's use as well as effects on resource management. Marine mammals, sea turtles, sharks, and sea birds that are caught incidentally in the conduct of fishing operations are now also referred to as bycatch. In most areas of the world there is no value to the fishermen in catching these species (There are some notable exceptions!) thus we include them in the non-commercial catagory. In fact, it can be quite costly to the fisherman measured by time lost, lost catch, and gear damage. One of the most difficult aspects of non-commercial bycatch is ascertaining to what degree it is occurring since this bycatch is normally discarded and not recorded. Fishermen are very hesitent about providing information regarding these interactions for fear of overly restrictive measures being imposed. The environmental community has focused on this one issue, in many cases separating this problem from broader ecological questions on how to manage fisheries on a sustainable basis. It is important to have an understanding of what the related issues are before arriving at the best bycatch reduction strategies for each fishery.

A. Fish bycatch in shrimp fisheries

In a detailed survey of world bycatch and discard (Alverson et al, 1994), tropical shrimp trawl fisheries were found to account for one third of the estimated world discards. The discarding of fish in shrimp fisheries could be as high as 16.7 million mt (Andrew and Pepperell, 1992). Alverson et al (1994) place total fish bycatch in shrimp fisheries at about 11.2 million mt and the discarded portion at about 9.5 million mt. Where modern trawlers replace artisanal fisheries discarding tends to increase unless an effort is made to develop markets for the bycatch. The larger more modern trawlers tend to have longer trips and thus are less likely to retain for market low valued fish (Pauly and Neal, 1985). This lowers the supply of cheap protein for local populations of people and their animals.

Fourteen of the top twenty fisheries with the highest discard ratios by weight are shrimp fisheries; ratios as high as 14.7 kg of fish for every kilo of landed shrimp. Discarding in the shrimp fisheries in Thailand, Indonesia, and the Philippines are estimated to represent 50% of the total regional bycatch. The situation is the same for the West Indian Ocean (India and Pakistan) and much higher, 80%, in the West Central Atlantic (Gulf of Mexico). Shrimp fisheries in temperate climates primarily discard juvenile gadoids and flounders. In tropical and subtropical areas the fish bycatch consists of many more species including jacks, goatfishes, flounders, and rays (Alverson et al, 1994). With fish bycatch being as high as reported, scientist still have concluded that reducing this bycatch will not impact shrimp stocks (Gulland and Rothschild, 1984; Sheridan et al., 1984). This conclusion still begs the question of wider impacts.

Survival of discards from shrimp trawlers may be low. Hill and Wassenberg (1990) estimated that as little as 2% of the fish and cephalopods discarded in the Torres Strait, Australia prawn fishery survive. Crustacean survival rates were higher at 51% (ranging from 23% to 80%).

In the Gulf of Mexico shrimp fishing has been indicated in the decline of two finfish stocks; Atlantic croaker and red snapper (Tillman, 1992). The red snapper are primarily small juveniles that are colocated with the shrimp (Watson, 1992). Species assemblages have also been shown to change due to shrimp fisheries (Pauly and Neal, 1985; Harris and Poiner, 1990).

Discards from shrimp fisheries have been shown to support seabird populations in Moreton Bay, Australia (Blaber and Wassenberg, 1989). There is an indication that discards of fish from shrimp trawl operations may increase food availability and consequently, shrimp populations. Lower bycatch levels may cause fishermen to tow longer. This in turn can reduce the quality of the target shrimp and increase the mortality of the discard.

In the Norwegian fishery for *Pandalus borealis* the fish bycatch consists of marketable and unmarketable fish. To control the bycatch the Norwegian authorities would close an area to shrimp trawling if the bycatch of juvenile cod and haddock, observed by government inspectors, exceeded 3 fish per 10 kgs of shrimp (Karlsen and Larsen, 1988).

B. Turtle bycatch in shrimp fisheries

Sea turtle bycatch in shrimp trawls in the fisheries of the Southeastern United States is the largest source of mortality for those species in that country. During the 1980's, over 50,000 turtles died due to the shrimp trawl fishery in USA waters.

C. Undersized shrimp

Shrimp that are discarded because they are too small to market or, if landed, would of attained a higher market value if allowed to grow larger, represent a serious economic loss to shrimp fisheries. It was estimated that after a short closure off Texas, USA, market value of shrimp increased almost $10 million due to increased growth (Poffenberger, 1992). Some stocks/species of shrimps spend their juvenile stage inshore and move offshore as they mature. While inshore the shrimp are commonly harvested by small boats using traditional gears (artisanal fisheries) and when they move offshore larger vessels employing trawls (industrial fisheries) are the common harvesters. Optimizing the yield per recruit in this situation has been more of an allocation/political decision than a technical one involving gear design. Juvenile shrimp may best be protected by time/area closures but this also affects allocation of the resource especially in inshore areas. Legal regimes which have resource allocation consequences may be desirable in their own rights, socially and economically, as well as having aditional conservation objectives.

D. Technical solutions to bycatch

There has been a considerable amount of work trying to separate species within a small mesh shrimp trawl to allow one or more groups to escape. Shrimp/fish separation and turtle excluder devices (TED's) are classic examples. Attempts to reduce the capture of fish in shrimp trawls have been underway for decades. Increasing mesh size in the codend was the first strategy undertaken to reduce the take of juvenile shrimp and fish. In Australia, 40 mm square mesh panels in the codend have beem shown to reduce the bycatch of relatively fusiform juvenile mulloway, *Argyrosomus holoepidotus* (Kennelly et al, 1992). Haulback delays may improve the effectiveness of square mesh escape panels for some species, though there is concern that there may be greater post-trawl mortality for fish that escape at the end of a tow (Broadhurst et al, 1996). In Iceland, square mesh codends reduced the catch of age zero gadoids significantly with a 10-20% loss of smaller shrimp (Thorsteinsson, 1992). However, most of the fish bycatch in shrimp fisheries is larger that the target shrimp so efforts had to focus on means to separate the species in the trawl. In the USA, the modifications are known as Bycatch Reduction Devices (BRD’s). There are many variations of shrimp sorting type trawls.

Work on selective shrimp beam trawls began in 1964 in the Netherlands to reduce flatfish bycatch in the brown shrimp (*Crangon crangon*) fishery (Boddeke, 1992). A selective panel was designed to make use of the behavior difference between shrimp and flatfish. Shrimp react to the towed gear by jumping and pass through a large mesh panel. Flatfish swim low and are lead by the selective panel to an opening in the belly of the net. This gear is in use in Europe and is very effective in clear water. There can be a problem with seaweed blocking the meshes of the selective panel.

In Norway, research activities to reduce fish bycatch in shrimp trawls began in 1975 based on work underway in the USA at that time (Karlsen and Larsen, 1988). Initial tests involved the use of vertical mesh panels in the trawl and this evolved to the testing of radial escape sections and square mesh cod ends. It was found that the effectiveness of inserted panels was a function of how accurate the panel was mounted in the trawl and the panel's mesh size. On average, about a 10% shrimp loss was associated with the use of some panels and much higher with other designs. Large quantities of flatfish tend to block the panels increasing shrimp loss. Spiny fish, such as redfish, mesh inthe panels and also increase shrimp loss. Panel operations are also affected by tides and currents, catch size, and changes to trawl rigging.

Improving the size selectivity of shrimp trawls by altering cod end mesh size has been problematical. Valemarsen (1988) found in the Norwegian shrimp fishery no difference in size selctivity when testing 35 to 45 mm cod end meshes when catches exceeded 500 kgs.

TED's have reduced the take of sea turtles during trials by 97% with insignificant reductions in shrimp catch in the Gulf of Mexico. Once the USA government required the use of TED's, the industry came up with five improved designs that worked better than the government's TED. They are lighter, simpler, and less costly. One design, the Andrews TED, is actually a net within the net. The inner net is large mesh that allows the shrimp to pass through to the cod end of the outer net. The inner net directs the turtles and large fish out a flap-covered exit hole in the trawl bottom. Even with these industry designs, it is estimated that bycatch reduction devices may cost participants in this fishery nearly $30 million in capital outlays over a ten year period. Of course, fishery closures would be even more costly. TED's also can reduce fish bycatch and where specifically used for this purpose become BRD’s; the amount of reduction is a function of the type of TED/BRD and the species present. Factors such as bar spacing/mesh size, funnel design, bottom/top exclusion, and flaps all affect bycatch exclusion (Harrington, 1992). The addition of accelerator funnels and leading panels to the TED/BRD increased separation rates by as much as 78% in daytime fishing and 50% during nighttime fishing (Watson and Taylor, 1991).

The work on TED's has lead to renewed research on bycatch reduction devices (BRD's) for fish. One device is known as a fish-eye or Florida Fish Excluder. It is a small rigid frame that is installed in a cut slot in the cod end or extension that provides an opening for fish to escape. Another method is a cylindrical large square mesh section of the extension associated with an accelerator funnel. Fish-eyes have reduced fish catch by over 50% in some tests, being more effective on some species over others. They do however have shrimp loss of 5-10% in preliminary trials. The large mesh sections have also reduced catch of certain finfish without shrimp loss. Gear handling during haulback with these devices and weather seems to impact the results.

In TED equipped trawls, shortening the length of the codend can increase fish escapement during haulback as the codend is less likely to collapse and block escape

(Harrington, 1992). In Brazilian waters, tests of shortened trawls without TED's reduced bycatch by 17% while increasing shrimp catch by 5% (Conolly, 1992). The increased shrimp catch is due to the fact that the shortened nets have less netting thus less drag and, correspondingly, have a wider spread at the net mouth. The shortened nets are also less expensive. However, on larger vessels there are limits to how short the codend can be made due to handling problems (dumping the catch on deck). Cutting small holes, or "snake eyes", in the vicinity of accelerator funnels associated with the TED's also facilitates fish escape in clear water during daytime tows.

Another approach has been the use of "hummer wires" in the trawl (Watson, 1992). These are small diameter wires attached to a frame that vibrate emitting a low frequency sound. This is used to direct fish towards escape openings in the trawl. Hummer wires improved exclusion of fish that exhibit an optomotor response, ie, schooling fish. These fish are less likely to try to escape from a trawl than fish that do not school.

In the USA Gulf of Maine shrimp fishery a combination of large mesh in the lower belly, shorter legs, and an accelerator funnel resulted in lower catches of gadoids and flounders (Kenney et al, 1991). In the Scotian shelf shrimp fishery, groundfish bycatches were limited to 10% of the shrimp catch which had the affect of closing the shrimp fishery before the shrimp TAC was attained. In 1991 a shrimp separator grate (Nordmore grate) was introduced (25 mm bar spacing or less) that was placed into the 40 mm cod ends of the trawls. The Nordmore grid was developed in Norway (Isaksen et al, 1992). Experimently, bycatch reductions of 60 to 99% were obtained on the Scotian shelf. Bycatch was reduced in commercial use so that by 1994 the shrimp TAC could be taken without closing the fishery due to fish bycatch. However, the problem still remains of small fish that pass through the grate and are retained. In this example the separator grate was used to solve an allocation problem more than a conservation problem. Experiments with new grid designs are ongoing (Larsen, 1996). Currently, separator grates have routinely outperformed other trawl net modifications in the Gulf of Maine (Schick, 1992).

Some authors have expressed the concern that complicated and expensive modifications to trawls as discussed above will not meet with acceptance by traditional fishermen in the Southern hemisphere (Conolly, 1992). The fact is, they haven't met with acceptance in the Northern hemisphere. The Gulf of Mexico shrimp fleet claims BRD equipped trawls have significant shrimp losses. The fishermen claim as much as 40%; the scientific community claims less than 10% shrimp loss. The differences may have to do with the weather conditions when the gear is hauled. The impetus to require BRD's in trawls is the mortality associated with the high bycatch of juvenile red snapper; a fact that the fishermen also do not accept.

IV. Habitat impact

A. Towed gear

The effects of towed gear on the bottom habitat and its potential for impacting the entire food chain is probably one of the most important issues related to fishing gear, as well as the least understood. It is known that habitat impact is related to the substrate type, sediment size, current velocity, the organisms present, and the gear being used. The gear parameters include gear type, weight, and frequency of use. What is not very well know is the long-term impact on an ecosystem that undergoes continual disruption by towed gear. We do know that habitat alteration is a major cause of extinction on land. Even though towed gear impacts are hard to quantify, and in many cases anecdotal, now may be an opportune time to consider alternative passive means to harvest the resource.

The impacts of towed gear on the productivity of the ecosystem may have been masked by the impacts of over-harvesting. One thesis is that the productivity of the ecosystem has been significantly and negatively altered by towed gear to the point that it is easily over-harvested. Catch and discards of commercial species (the outputs) are only one aspect of this problem. There are other impacts (to inputs of production) that affect productivity such as alteration of substrate, sediment resuspension, destruction of benthos, and disruption of species behaviours. This paper will discuss these issues after first presenting a brief history of trawling impact.

The first concerns about the impact of fishing gear on habitat were expressed by fixed gear fishermen opposed to the introduction of towed gear. Groot (1984) references such concerns expressed as early as six centuries ago in England, the Netherlands, and France. The towed gear was an early form of beam trawl. The complaints put forth the proposition that the towed gear dislodged rocks and moved substrate thus crushing and killing the important bottom organisms that provided food and shelter to the food fishes. Over the centuries complaints continued to be voiced but negative impacts were hard to prove with the scientific tools available.

The primary towed gear types up to the mid-nineteenth century were the beam trawl and the shellfish dredge. The largest of these gear types were towed slowly by sailing vessels, without powered deck equipment, and consequently were relatively small, light, and constrained to shallow depths. Otter trawling began with the invention of the otter board. Scofield (1948) credits the use of the otter board to English sportsfishermen who utilized the device to poach fish from closed trout streams. The boards were used as a depressor to keep their fishing lines down and to the side of their skiffs. Commercial fishermen adapted the concept to trawling in the early 1860's.

Otter trawls started to replace beam trawls in the English fisheries during the 1860's. This process was rapidly accelerated in 1870, when the first steam trawler, Berta, was launched in England. Other European countries, Germany and Holland, were soon to follow. The primary reason for this gear change was that with the advent of steam powered trawlers, the fishermen were able to increase the size of their gear. This is difficult to do with the hard to handle beam trawl but a relatively simple task with an otter trawl.

From the 1930's to the present, research in Europe and North America focused on increasing mesh size of trawl cod ends to solve the problem of small fish retention. Recently, efforts have focused on how to make trawls more species selective. This research does little to solve the problems that may be inherent to bottom towed gear.

Today we have enough evidence indicating that fishing can change the species complex in an area, either by altering the physical habitat or by selectively destroying sessile organisms that occupy the habitat (Sainsbury, 1987). The destruction can be due to harvesting and subsequent removal of sessile species, sediment resuspension, mechanical contact with the gear, or physical movement of substrate. In most cases, however, it is still difficult to separate out the long-term impacts of fishing from natural processes and other human-induced impacts. Insidiously, the act of fishing may keep ecosystem production depressed, but undetectable, by chronic sub-lethal effects on reproduction and feeding.

The short-term impact of otter trawling on sand and mud habitat has not been seen to be significant (Spurr, 1977; Estrella, 1989). Graham (1955) and Gibbs et al.(1980) found no detectable changes in benthic fauna as a result of otter trawling in sandy habitat. Smith and Stewart (1985) felt that the effects of trawl door furrows in mud bottom were of short duration. There is, however, concern about the impact of sediment resuspension on the ecology.

Otter trawls can generate a significant sediment cloud from the doors and footrope (Main and Sangster 1981). Sediment resuspension by otter trawl gear can be highly significant in certain environments and in certain seasons when compared to natural processes (Churchill 1989). Churchill found that sediment resuspended by trawling can reach significant levels 10 m above the bottom and remain in suspension at relatively high concentrations for at least a day or more. He estimated that in depths of 100-130 m the amount of sediment resuspended by towed fishing gear can be many times greater than that resuspended by currents or storms.

In high energy environments, such as areas of strong tidal currents, heavy fishing pressure may alter the bottom by continually suspending and causing finer sediments to be flushed away (Anon 1973). Working the bottom attracts predators to feed on exposed benthos; the net impact of this is unknown. Potential positive impacts may include higher production of certain species that feed on the exposed benthos. Potentially adverse effects include introducing previously trapped pollutants into the water column, smothering eggs and small organisms, retarding metabolic functions in filter feeders, altering the ecosystem structure, destroying habitat, changing behavior, etc. (Cruikshank and Hess 1975). Sediment resuspension can increase the rate of benthic/pelagic nutrient flux which could lead to plankton blooms (Messieh et al. 1991) which can have positive or negative effects. Yamamoto (1960) found that sediment resuspension caused by working the bottom can create anaerobic turbid conditions capable of killing scallop spat. Anderson and Meyer (1986) found that resuspended sediment decreased the feeding efficiency of filter feeders.

Fahraeus-Van Ree (1990) concluded that cloudy water resulting from otter trawling "...may negatively influence the physical (visual, auditory, hydrodynamic, tactile and bioelectric) and chemical (pheromones) interactions between cod males and females as well as the interactions between eggs and milt." Fahraeus-Van Ree's review includes several other observations as follows. Newly released eggs are adhesive thus suspended sediment can easily cover the egg membrane resulting in metabolic disturbance and eventual cell death. Cod larvae moving down in the water column to the bottom may be negatively impacted by suspended sediment in that it can diminish their chances of locating prey organisms as they are visual feeders at this point in life. They may also have respiratory difficulty if sediment covers their epithelia hindering gas exchange.

Stevens (1987), working with New Zealand scallops, found that sediment clouds generated by towed fishing gear have the potential to kill scallop spat. Equivalent turbidity levels in laboratory tests resulted in scallop mortality. High levels of fine silt particles resulted in complete mortality of juveniles (<20 mm) and somewhat less mortality in larger scallops (70 mm). Suspended sediment at lower levels decreases scallop feeding efficiency inhibiting growth and survival. Metamorphosis of larvae may be affected by sediment resuspension. Resettling of sediment can cover surfaces preventing spat settlement on those surfaces. Studies in New Zealand on reseeded scallop beds found 20% survival of spat on untowed beds versus 0.8% survival on beds open to trawling (Bull, 1986). The relative roles of sediment suspension and mechanical damage resulting in this mortality is unknown. Large sea scallops (100 mm) have also been found to have a low tolerance to suspended material (Cranford and Gordon, 1992).

The impact of trawling and dredging on hard bottom has not been widely documented, but possibly can be more significant than on sand or mud bottom for a number of reasons. The first is that hard bottom trawl and scallop gear is heavier. Secondly, the organisms on hard bottom may be more susceptible to injury. Most importantly, heavy towed gear may actually change the hard bottom characteristics by moving and breaking up substrate. On the other side of the argument, it can be said that hard bottom trawl gear is designed to roll over the bottom, as opposed to be dragged through it, thus minimizing any damage. Small organisms can escape underneath a roller-rigged footrope better than a continuous sweep commonly fished on sand/mud substrates. Where rollers do come into contact with the bottom, crushing of organisms will likely occur. On previously untowed bottom, coral formations, sponges, and other erect structures will be severely damaged. Behnken (1993) reported significant amounts of coral destroyed by trawl vessels fishing new grounds in Southeast Alaska. Main and Sangster (1979) have shown that different door designs will have different visible impacts to the bottom. Some tend to push rocks out of the way, while others ride over the boulders.

There has been some documentation of trawl impact on "live bottom" areas of the southeastern United States. Live bottom was first described by Cummins et al. (1962) as bottom containing sponges, coral, rocks, and shell, and is generally considered the most productive area of the USA southeastern shelf for commercial reef fish such as snapper. In a study using a research trawl on this type of hard bottom, Dolah et al. (1987) found that habitat damage did occur even after one pass. However, after one year, with no subsequent trawling, the damage could no longer be detected, due to healing and growth. The authors were concerned about the reduction in height of sessile organisms due to repeated trawling as the vertical profile is important to many species for protection from predators.

Wenner (1983) found that tows in sponge-coral habitat in the South Atlantic Bight sheared off sponges, soft coral, and attached invertebrates. He concluded that trawls reduce the amount of attached invertebrate growth and sanded over attachment points thus inhibiting recolonization. This in turn reduces refuges for decapods and other organisms that are food for larger benthic feeders, in effect, reducing productive fish habitat.

These conclusions are supported by other research such as that of Young and Sainsbury (1985) in Australia. They found that on similar bottom, continuous commercial towing over a period of 16 years, shifted the species complex from that associated with sponges and corals, to that associated with open sandy bottom. The impact of trawling in the inter-reef areas is less clear (Hutchings 1990).

Long-term changes to habitat specifically due to fishing are hard to fully document, but there are some strong indications fishing induced changes have occurred (Jones 1992). Reise (1982) had documented long-term changes in species composition and abundance in the Wadden Sea that in some cases he attributed to fishing, but not specifically otter trawls. Pearson and Barnett (1987) review a downward trend in species diversity and abundance, in the Limfjord in Northern Denmark, that some had attributed to fishing, but in fact may have been due to organic enrichment of sediments by other causes.

The impact on the bottom of a beam trawl is similar to that of otter trawls. These impacts are dependent on substrate type and currents as well as the gear characteristics. The latter for beam trawls includes weight of tickler chains per unit length, chain spacing and numbers, and towing speed. The gear leaves physical marks or tracks in the substrate, ranging from barely visible to obvious, which may persist from minutes to days. Depth of tickler chain penetration varies from 0 to 27 mm, the latter caused by six chains on mud bottom (Bridger 1972). The most recent concerns expressed regarding beam trawl impact on habitat have to do with the amount of repeated tows, or fishing effort, to which a particular area may be subject. Areas vulnerable to trawling may see a change in benthos composition, but to what degree depends on the distribution of fishing effort in the vicinity (Rijnsdorp et al. 1991).

About 1970, ICES member countries agreed to examine the issue of beam trawl impact and a series of research projects were initiated. The major focus was on the weight and number of tickler chains as this is what differentiated the gear from otter trawls. Otter trawl fishermen were saying that the beam trawls dislodged rocks from the bottom and thus made it untowable for their gear. The beam trawls were also aledged to destroy far more benthos then otter trawls.

Cole (1971) stated that on certain bottoms, where stones were embedded in the substrate, beam trawls with heavy tickler chains, may make the bottom unworkable by otter trawls. In the same article (Cole 1971), Dr. Korringa of the Dutch Ministry of Fisheries, speculated that working the bottom might increase overall productivity.

Margetts and Bridger (1971) found beam trawl tracks were readily visible on muddy bottom but barely discernable on hard sand. They reported that the sediment cloud, generated by the gear on both substrate types, had not settled even after ten minutes. Bridger (1972) found that heavier beams with wider shoes did not leave grooves in the bottom, but lighter beams with narrow shoes left grooves 6-12 mm deep. He also found that the substrate was firmer after the passage of the gear, possibly because the lighter materials were placed into suspension and carried away. Groot (1972) found that tracks left by beam trawls were erased in times ranging from 25-150 minutes in sand and mud bottom.

Impact on benthos

Valentine and Lough (1991) studying Georges Bank reported "In untrawled, gravel-dominated areas of the Northern Edge and Northeast Peak, there exists a biologically diverse community dominated by abundant attached organisms. The presence of these organisms certainly increases the fine-scale, biological roughness of the sea bottom, and, by modifying the sea bed, they may play an important role in the fisheries habitat. By contrast, in heavily trawled areas of the gravel habitat, this community is poorly represented, and the bottom is relatively smoother."

Researchers have long recognized that bottom fishing operations induce additional mortality to benthic organisms that are either not caught or not landed (Caddy, 1973). This incidental mortality may result from mechanical processes (ie., injury to species physically encountering the gear during fishing; crushing/damaging species due to dredge passage over animals on the bottom; shell breakage of species compressed (within the gear itself) or on-deck handling and culling procedures (i.e., dumping of catch from the gear; prolonged air exposure on-deck during sorting and culling; shovelling of undersized animals overboard) (Medcof and Bourne 1964; Caddy 1973). Also, alterations to the sea bottom by the gear (i.e., churning up sediments; dislodging sand/mud into shellfish) may weaken animals making them more susceptible to predation, kill them outright, or reduce the favorableness of the habitat for survival, spat settlement, or reproduction.

Species behavior

Fahraeus-Van Ree (1990) performed an extensive literature review on the potential impact of trawling on the reproductive success in Atlantic cod. The review points out that reproductive success is a function of courtship behavior which is influenced by the presence of pheromones (chemical substances released by the animals). Many species have a complex courting and mating behaviors that involves establishment of territories, visual displays, and noise making. This pattern of behavior is very delicate and can be disturbed by stress-inducing factors. In addition, stressed females produce fewer fertilized eggs. Fahraeus-Van Ree concluded that spawning fish are negatively impacted by trawling.

Trawling activity may physically disburse spawning fish; disrupting male territories and breaking up courtship behavior. Trawling may also disburse eggs and milt resulting in less fertilization. Noise generated by trawling may also interfere with spawning behavior. Pheromones can be disbursed by trawling thus also disrupting spawning. The net effect of trawling activity may result in stressed fish leading to high fertilization failure.

Stokesbury and Himmelman (1993) studied large and small scale distribution of scallops in two unfished scallop beds. Large scale distribution was strongly associated with substrate type; gravel and gravel/sand. Small scale distribution was contagious in clumps. The short distance between scallops within clumps, the high proportion of clumps with both sexes present, and an average of three scallops per clump suggest high fertilization success within clumps. They suggest that the small scale aggregation of scallops is an adaptation to increase fertilization success, and if this is true, disturbance of these aggregations may decrease reproductive success.

There are other operating factors associated with towed gear that may be more important to the sustainability of harvests than just catch. Unfortunately, this hypothesis is very difficult to prove without eliminating towed gear from large areas.

It is hard to imagine that the fishing power of several hundred small trawlers can have a significant impact on a resource, especially when their catching efficiency is so low. Efficiencies of these gear types have been estimated to run between 10-20% by gear technologists. However, the fishing grounds are subject to repeated towing. Churchill (1989) reported as many as 20 trawl tracks per 100 square meters of bottom offshore southern New England. Once productivity is knocked down by the impacts of towed gear, a much lower level of towing is needed to maintain the lower state of productivity. Consequently, even large reductions in towed fishing effort would not cause productivity to increase as rapidly as it would with no towed effort.

Jones (1992) refers to work by Chong et al. (1987) discussing the 1980 Indonesia ban on trawling. The ban on trawling in this fishery, primarily on prawns with landings between 130,000 - 200,000 mt, did not reduce landings and in fact increased profitability. The reasons included recovery of stocks and improved value of catch. Further, there was a redistribution of wealth, derived from the fishery, from large offshore trawling companies to local communities which also had the effect of increasing profitability.

Bottom towed gear may be inappropriate to harvest finfish and shellfish over many types of bottom habitats. It would take significant time, money, and manpower to prove this hypothesis to the point of being legally defensible. The complexity of ecological relationships are hard enough to understand on land, virtually impossible under 100 meters of water. The best approach may be to close a large area to towed gear but allow fishing to continue with hooks and traps. Sainsbury (1988) reports on a similar approach in the Northwest shelf area of Australia where pair trawling was banned from two large areas and allowed to continue in a third. The approach was chosen because of the uncertainty in ecological models used to predict outcomes.

Sainsbury explains "...fisheries management of communities is conducted with considerable uncertainty about resource dynamics, and is largely empirical (even if this is not explicitly recognized). Under these circumstances it is highly desirable to evaluate the implications of recognized uncertainties to proposed management actions, and to introduce new management measures in such a way as to provide information which will be of management value in the future. The extent to which short-term revenue should be compromised to gain information about resource dynamics will depend on both social acceptability and the value of the information in leading to higher revenue in the long term."

V. Evaluating appropriate harvesting methods

VI. Literature review

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REFERENCE #: G001

Kenney, J., A. Blott, and J. T. DeAlteris. 1991. Shrimp separator trawl experiments in the Gulf of Maine shrimp fishery. Proc. Fish. Conservation Engr., Workshop. Rhode Island Sea Grant. p. 6-11.

A. Gear construction and operation

"The concept of selective shrimp trawls is not new. Trawl design modifications have been evaluated in shrimp fisheries for separating finfish from shrimp, with varying degrees of success (West et al. 1984; Averill 1988; Watson 1989; Watson and Taylor 1990). The techniques utilize behavioral and size differences between shrimp and finfish, and include horizontal separator twine panels, large mesh escape panels, deflecting grids, accelerator funnels, and others. The basic modifications to the nets evaluated in this project were: large mesh in the belly area and a funnel accelerator ahead of the trawl cod end." p. 6.

D. Fishing mortality

"The discard of finfish bycatch in the Gulf of Maine northern shrimp trawl fishery is considered a serious problem. The species-specific discard rate varied from 17 percent for winter flounder to 95 percent for silver hake in 50 tows made by commercial trawlers during the period 1985-1989 (Howell and Langran 1990). Studies by Jean (1963) and Howell and Langren (1987) suggest a very high mortality for discarded finfish in the western North Atlantic fisheries. The discard problem has two major facets; direct wastage in throwing fish back into the sea and loss of future catches of larger animals through the mortality of small individuals (Saila 1983)." abstract

"...compared to the tropical shrimp fisheries where 10 kg of finfish bycatch is captured and discarded for each 1 kg of shrimp captured, the Gulf of Maine shrimp fishery is not nearly as wasteful. The results of this project indicate that an average finfish bycatch for the control trawls is 0.43 kg of cod and dab per 1 kg of shrimp, and for the experimental trawls, 0.35 kg of cod and dab per 1 kg of shrimp. For the composite catches of all control trawl tows, approximately 73 percent of the cod catch was undersize (<19 in, 48.3 cm) and discarded; additionally, 98 percent of the dab catch was undersize (<14 in, 35.6 cm) and discarded."

"...it appears that large mesh (30 cm) in the lower belly, shorter legs (9 m vice 28 m), and an accelerator funnel can result in significantly reduced catches of either cod or dab." p. 11.

REFERENCE #: G002

Watson, J. W. and C. W. Taylor. 1991. Research on selective shrimp trawl designs for penaeid shrimp in the United States. Proc. Fish Cons. Engr. Workshop. Rhode Island Sea Grant. p. 50-59.

B. History and statistics

"Investigators have reported finfish catch rates between 2.8 and 18.0 kg for each kilogram of shrimp caught (Blomo and Nichols 1974, Chittenden and McEachran 1976, Bryan 1980, and Juhl et al 1976). The most recent study by Pellegrin et al (1985) estimated fish bycatch for the Northern Gulf of Mexico penaeid shrimp fleet at more than 510,000 mt."

D. Incidental fishing mortality

"The incidental catch of finfish by shrimp trawling gear is a significant source of mortality affecting the conservation, utilization, and management of finfish stocks in the southeastern United States."

"...the turtle excluder device (TED), was developed by NMFS to reduce the incidental capture of endangered sea turtles by shrimp trawls...Research during the development of the TED led to new finfish separator designs based on modification of water-flow characteristics in the trawl. The design uses webbing funnels to accelerate water in the cod end of the trawl, and leading panels and openings to exclude finfish. The separation technique utilizes the differences in swimming ability and behavior between shrimp and finfish to reduce the finfish catch. Separation rates of as much as 78 percent during daytime fishing and 50 percent during nighttime fishing, with no significant difference in shrimp catch rates, were achieved during evaluation of the technique."

This paper contains a review of selective shrimp trawl research in the United States since 1973.

REFERENCE #: G003

Thorsteinsson, G. 1992. The use of square mesh in the Icelandic shrimp (*Pandalus borealis*) fishery. Fisheries Research 13: 255-266.

C. Selectivity

Before 1967, the Icelandic shrimp fishery was conducted by low powered boats on inshore grounds using small trawls with short bellies. Small gadoids and herring were able to out-swim the slow gear and were thus not subject to capture. The discovery of offshore shrimp grounds in 1967 introduced bigger trawl designs into both inshore and offshore fisheries. The larger trawls caught 2.3 times more shrimp than the smaller trawls but also increased the catch of small fish. In one experiment the small trawl caught 22 fish per hour versus 314 fish per hour for the larger trawl.

Attempts to reduce bycatch included "...the use of shorter bridles, longer chains between fishing line and footrope, and the hauling of the trawl with the engine disconnected from the propeller. Very soon the conventional footrope was replaced by bobbins which were originally considered to reduce the bycatch of young fish but actually resulted in shrimping on harder ground where small fish were often more plentiful."

Other methods to reduce fish bycatch and catch of under-sized shrimp included closing areas, increasing cod end mesh size, and providing extra slack in the net side panels.

Square mesh cod ends were found to decrease the catch of 0-group fish drastically and reduce undersized shrimp significantly. There was also a 10-20% loss of legal shrimp but these were usually of the smaller, less valuable size.

D. Incidental Fishing Mortality

In 1974 management guidelines based on economic considerations were adopted. "In these calculations the prices of shrimp and fish species were taken into consideration (Palsson and Thorsteinsson, 1985). The guidelines indicate the number of small gadoids and other fish species allowed per 1000 kg of shrimp."

In 1974 "... the shrimp fishery in Isafjardardjup...had killed small gadoids which would have yielded a catch of 1600 tons some years later." This represented 40% of Iceland's shrimp catch for that year.

REFERENCE #: G004

Andrew, N.L., K.J. Graham, S.J. Kennelly, and M.K. Broadhurst. 1991. The effects of trawl configuration on the size and composition of catches using benthic prawn trawls off the coast of New South Wales, Australia. ICES J. mar. Sci., 48: 201-209.

This study compares the catch rates of fish and crustacea in triple-rigged trawls, and in single trawls with and without sweeps of 40 m and 140 m length, off the coast of southwestern Australia. Other studies have shown that the number and size composition of catches are influenced by the length of sweeps. Most trawlers in the eastern king prawn fishery off Australia formerly towed single trawls but most are now triple-rigged. Consequently, there has been an increase in incidental catch, mostly demersal fishes and invertebrates. Fishermen profit from some by-catch, and species such as red spot whiting are often targeted.

The catch per swept area and size selectivities of four configurations of prawn trawls were assessed during night-time trials; trawl configurations compared were: single trawl with 7 m bridles, single trawl with 40 m bridles, triple-rigged trawl, and single trawl with 140 m sweeps. Catch comparisons were made between Australian red spot whiting, sand flathead, shovelnose lobsters, Eastern king prawn, and brown tiger prawn.

Results are discussed in terms of operational and catch differences between trawls. Mainly, sweeps were found to herd Australian red spot whiting and sand flathead but not prawns and shovelnose lobsters. Single trawls with long sweeps caught significantly larger red spot whiting and sand flathead than any other trawl configuration. Triple gear caught more smaller red spot whiting than other configurations but this effect was not evident for sand flathead.

The relationship between catch rate and sweep length should be known in order to compare assessments of stock abundance and species composition drawn from trawls with different sweeps. If incidental catch is to be monitored in prawn trawl fisheries then the use of long sweeps should be regulated.

REFERENCE #: G005

Andrew, N.L., and J. G. Pepperell, 1992. The by-catch of shrimp trawl fisheries. *Oceanogr. Mar. Biol. Annu. Rev.*, 30, 527-565.

This report draws together the literature on shrimp by-catch and reviews the state of research on by-catch estimation, utilization, efforts for reduction, and impacts of trawling on ecosystems. Shrimp trawl fisheries make an important contribution to the total catch of the world's marine fisheries, and in so doing generate a tremendous amount of incidental mortality to other fishes, particularly fin-fish. In the great majority of the world's shrimp fisheries more by-catch is caught than shrimps.

There are several reasons to minimize by-catch reported in the literature. Killing commercially important species or protected animals, disrupting the food web, contaminating the catch via rotting organic material on trawl grounds, and conducting inefficient trawl tows are all drawbacks to fisheries with a large amount of incidental catch. A direct approach to avoiding by-catch is to design fishing gear that allows by-catch, particularly turtles and fin-fishes, to escape. These devices, known as TEDs, allow non-targeted species to pass through panels while allowing target species to pass through to the codend. TEDs have been used mainly for turtles, though also for fin-fish and in other fisheries (for pandalid shrimps in New England, for example, and for groundfish in Norway).

Selective trawl designs have been used which incorporate chutes, pockets and covers, as well as 'skylight' panels, to allow by-catch to escape. Trawls have also been designed to retain by-catch in a second codend, while electric fields have been used to avoid by-catch all together.

Trawling is considered to affect directly the stocks of species caught as by-catch. It also has indirect effects by possibly changing the abundance and composition of community assemblages. Differential mortality of predators and prey can lead to changes in food-web dynamics. The physical impact of trawling may change trawl grounds so they are suitable to different types of species. Moreover, discards from trawl fisheries make food available to surface predators, and have been shown to influence the behavior and numbers of scavenging species. The structure of benthic communities (abundance and species composition) also has been shown to change after trawling.

REFERENCE #: G006

Broadhurst, Matt K., Steven J. Kennelly, and Gerard O'Doherty, 1996. Square-mesh panels in codends and the effects of haulback-delay on by-catch reduction in the New South Wales oceanic prawn-trawl fishery, Australia. *Fish. Bull.* 94(3): pp xx-xx.

This study addresses the effectiveness of square-mesh panels in reducing by-catch from the New South Wales oceanic prawn-trawl fishery and assesses the effects on catches from haulback-delay using the panels. Incidental capture and mortality of animals other than the targeted eastern king prawn in NSW may reduce the yield of stocks that form the basis of other fisheries. Square-mesh panels in codends have been successful in reducing by-catches. Other studies have not addressed behavior patterns of escaping fish nor the period during tows that escape occurs.

In the NSW prawn fishery there is a delay of up to 15 seconds between slowing the vessel and engaging the winch to haul in the trawl (haulback-delay). During this time, the degree to which fish escape varies per species. The effects of the haul-back delay on fish behavior needs to be addressed in order to interpret adequately the effectiveness of the square-mesh panels.

Two codend designs with panels inserted in different configurations (length-wise versus width-wise) were compared against a conventional design. Both of the modified codends significantly reduced the weight of discarded by-catch, and one significantly reduced the number and weight of red spot whiting. Neither reduced the catch of prawns.

A second experiment testing the effects of haulback-delay showed that juvenile whiting, an important commercial finfish, escaped from square-mesh panels in the trawl during a 10-15 second delay. There was no significant reduction in the number or weight when there was no delay in haulback, unlike other species which escaped continually throughout the duration of the tow. If fish which remain in the codend experience greater stress as other studies have shown, those fish escaping at the end of the tow may suffer greater post-trawl mortality than those which escape continuously.

Unless most of the escaping fish survive, square-mesh panels in codends may be of little value. Mortality of red spot whiting may be reduced by lengthening the panel or increasing its mesh-size. Not all species to be excluded behave in a similar manner and the effects of operational procedures can significantly influence the rate of exclusion of some species.

REFERENCE #: G007

Coale, J. S., and R. A. Rulifson, 1994. Comparisons of shrimp catch and bycatch between a skimmer trawl and an otter trawl in the North Carolina inshore shrimp fishery. *North American Journal of Fisheries Management* 14:751-768.

Researchers compare skimmer and otter trawl fisheries in North Carolina and the different fishing methods used with these gears. Amount of bycatch, amount of shrimp caught, bycatch composition, bycatch survivability, and length-frequency distributions of finfish species collected in each gear are compared. The purpose of the study was to determine if skimmer trawls can be used in North Carolina to reduce bycatch and improve bycatch survivability.

Brown shrimp, *Penaeus azetecus*, pink shrimp, *P. duorarum*, and white shrimp, *P. setiferus*, make up the commercial shrimp fishery in North Carolina. Fishermen typically use the otter trawl, an unselective type of gear which generates a considerable amount of bycatch. One and a half to eighteen kilograms of finfish may be caught for each kilogram of shrimp.

The skimmer trawl may reduce bycatch because it is pushed in pairs alongside the vessel, as opposed to behind the vessel like the otter trawl. Towed beside the vessel, each skimmer trawl tailbag can be retrieved every 30 minutes without stopping the vessel. Bycatch survival should be greater because the catch is dumped more frequently.

Results showed that on average, the skimmer trawl caught less bycatch (mean, 0.47 kg/min) than the otter trawl (mean, 0.66 kg/min), and had the lower bycatch rate (mean, 0.30 kg/min) and fish-to-shrimp ratio (mean, 1.38) during peak season for white shrimp. Organisms in the skimmer trawl showed greater survivability than those in the otter trawl. Skimmer trawls proved more effective in catching white shrimp, and otter trawls in catching brown shrimp. The strength of statistical comparisons was limited due to the two different methods of operation.

The lower bycatch rate of the skimmer trawl may be attributed to the reduced net spread compared to the otter trawl. Lower mortality observed in the skimmer trawl may be due to frequent retrieval of the tailbag and shorter culling time, the gear itself, or a combination of these factors. The skimmer trawl does not require use of a TED because the frequent tailbag retrieval should increase survival rates of captured sea turtles. Finfish bycatch may be reduced even further when Florida fish excluders are sewn into skimmer nets. Use of the skimmer trawl in the North Carolina shrimp fishery may increase white shrimp catch and reduce bycatch and mortality of most other species.

REFERENCE #: G008

Henwood, T., W. Stuntz, and N. Thompson, 1992. Evaluation of U.S. turtle protective measures under existing TED regulations, including estimates of shrimp trawler related turtle mortality in the wider Caribbean. NOAA Technical Memorandum NMFS-SEFSC-303 15p.

This study evaluates sea turtle catch and mortality by U.S. shrimp trawlers under current sea turtle conservation regulations, and provides a gross estimate of turtle catch and mortality for the wider Caribbean. Sea turtles are caught incidentally by shrimp trawlers in U.S. and foreign waters. Since 1987 turtles have been protected by Federal Sea Turtle Conservation Regulations (Federal Register, Vol. 52, No. 124, June 29 1987), otherwise known as Turtle Excluder Device (TED) Regulations, in the Gulf of Mexico and southwestern North Atlantic. Opposition to TEDs has been based on the argument that regulations are an economic burden and sea turtle mortality is negligent.

Inshore and offshore shrimping effort, turtle catch rates, turtle mortality rates, effectiveness of TEDs and tow time restrictions, and compliance with existing regulations, were analyzed in order to evaluate sea turtle catch and mortality in the United States. Several assumptions needed to be made in the analysis which may under or overestimate sea turtle mortality. Based on the analysis, approximately 4,360 turtles suffer mortality each year in the inshore and offshore U.S. Atlantic and Gulf of Mexico waters despite current TED regulations. This compares to a total of 13,112 turtles taken without TED regulations.

This mortality rate before TED regulations is approximately equal to that taken by the Mexican shrimp fleet (11,324), though this number could be higher because Mexican fishermen do not release turtles, and turtles may be more abundant in waters off Mexico. In Central America roughly 3,500 turtles are taken (and die), and in South America, roughly 10,600.

The mortality estimate in U.S. waters (4,360) is probably an underestimate. Current TED regulations have resulted in a 67% reduction in annual turtle mortalities. The authors note that, "annual shrimp landings have not changed despite alleged high shrimp loss rates associated with TED utilization. Expansion of TED requirements to all areas at all times of the year would result in a total reduction in shrimp trawler related sea turtle mortalities of 97%." It is essential to enforce conservation measures beyond U.S. waters in order to ensure that turtles are protected throughout their entire range.

REFERENCE #: G009

Isaksen B., J.W. Valdermarsen, R.B. Larsen, and L. Karlsen, 1992. Reduction of fish by-catch in shrimp trawl using a rigid separator grid in the aft belly. *Fisheries Research*, 13: 335-352.

This study describes the design, implementation, and effectiveness of a rectangular grid installed in a shrimp trawl to avoid the by-catch of fish. Designed in Norway, the aluminum grid with longitudinal bars is placed in the extension piece in front of the codend, angled 48º, with a fish outlet on the top. In front of the grid a funnel guides fish and shrimps toward the lower part of the grid.

Countries such as Norway and the USSR consider by-catch of fish in shrimp trawls in the Barents Sea and along the Norwegian coast undesirable. Major by-catch includes undersized cod and haddock, as well as small redfish and Greenland halibut. Since 1984, a separator panel of netting had been used in those coastal shrimp fisheries which exceed minimum by-catch levels. Redfish are difficult to separate with net panels; however, a rigid separator grid, the 'Nordmore'-grid, proved more successful. Using the separator grid, fishermen are able to fish on grounds that otherwise would have been closed due to the high by-catch of cod and haddock, while at the same time they are able to decrease the amount of sorting work on deck.

In evaluating the effectiveness of the grid, researchers investigated various distances between bars, dimensions of the grid, location and angles of the grid mount, grid materials, guiding devices, and sizes of the fish outlet. Installation, practical aspects, speed and angle measurements, and underwater observations of the grid are described.

In experiments using the separator grid, shrimp loss was low, (around 2-5%), and a higher percentage of large fish were released relative to small fish. The size at which fish were released varied per species. (Species included cod, haddock, Greenland halibut, redfish, and polar cod.)

Other by-catch prevention devices have been evaluated, though the separator grid has been the most optimal in terms of separating fish and avoiding shrimp loss. To get the best results, the grid must be designed and installed properly (aspects described in study). The authors recommend "coastal shrimpers (40-60 feet) use aluminum grids at least 0.7 m wide and 1.35 m long, while the bigger offshore trawlers use a 1.0 m wide and 1.5 m long grid, both with a bar separation of 19 mm and mounting angle of 48ª, which gives an acceptable shrimp loss below 5%."

Following these experiments, the separator grid was made compulsory in the northern coastal shrimp fishery from 1 March 1990, in the offshore fisheries from 1 January 1992, and in the Barents Sea and Spitsbergen waters from 1 January 1993.

REFERENCE #: G010

Larsen, Roger B., 1996. Experiments with a new, larger type of fish/shrimp separator grid and comparisons with the standard Nordmore grid. ICES FTFB W.G. Meeting, Woods Hole, 15-18 April.

This study compares use of the standard Nordmore grid and a new and larger type of fish/shrimp separator grid in reducing bycatch and increasing escapement of juvenile fish. Successfully used by shrimp fleets internationally, the Nordmore grid (standard off shore) measures 1.5m in length and 1.3m wide with a maximum bar distance of 19.0mm, and is operated at an angle between 50º and 45º. More effective separation of the smallest fish (0-group) needs to be achieved.

The new type of fish/shrimp separator grid, with a longer grid and a lower angle of attack, was tested during a cruise along Svalbard in July/August 1995. The purpose was to test whether the new style improved escapement of juvenile fish (0-group), as well as typical bycatch species like redfish and flatfish, and maintained a low and acceptable loss of shrimps comparable to the Nordmore grid.

The installation of the new type of grid is similar to the standard Nordmore grid, but the construction differs in the length (2.5 m versus 1.5m), and the way the crosswise strengthening bolts are fastened to the lengthwise bars. The large grid was tested at angles of 18º and 23º, while the Nordmore grid was tested at 48º.

Only two hauls were compared, though all species of fish (cod, redfish, Greenland halibut, and Long rough dab) seem to escape more easily with the new grid. Average loss of shrimps by weight was smaller with the new grid than with the Nordmore despite the large difference in angles of attack. The numbers of juvenile fish during this experiment were too high with both types of grids. Even at the lowest angle of attack (18º), the numbers of small fish retained exceeded the legal limit of 1 juvenile/kg shrimp catch. "It is therefore necessary to encourage work that can solve the bycatch problem of the smallest fish in the northern shrimp fisheries."

REFERENCE #: G011

Buckworth, Rik C. 1992.. Could trapping be a feasible additional method of fishing in Australia's northern prawn fishery? *In* International Conference on Shrimp Bycatch, Southeastern Fisheries Association, Tallahassee, Florida, May 24-27, 1992. pp.125-140.

History and statistics

Annual catches in Australia's northern prawn trawl fishery varied between about 7000 tons in 1990 and 13000 tons in 1974, valued currently around A$100 million. Most of the catch is exported to Japan. The 97% by-catch rate is the largest in the fishery and is similar to other tropical shrimp fisheries.

Gear construction and operation

Three main approaches to by-catch reduction have been suggested: changing fishing patterns, changes to gears, and the adoption of passive fishing gears such as trammel nets, traps, or pots. This study reviews the information concerning by-catch in Australia's northern prawn trawl fishery, and examines a practical and economic model for using traps as an alternative to trawling.

"Compared to trawling, trapping would minimize habitat degradation and greatly reduce fuel consumption. The considerable reduction in by-catch should minimize environmental concerns and conflict with other fisheries. Without the abrasion and crushing that occurs in trawling, and with the possibility of exploiting selectivity, trapping provides the opportunity to maximize the quality of the catch.

....Scenarios examined were conservative (described in report), with the objectives of indicating firstly the level of catch rate required for the easy transition of a small trawler to a trapping operation and secondly, to examine a more specialized alternative scenario. While it is possible that traps could target local concentrations more effectively than trawls, fishing strategies that could accommodate lower catch rates yet remain economically feasible would be most appropriate."

An Appendix is included which lists a full budget for one year's operation under the three scenarios. A structured program to test the method and experimentation with trap design, deployment methods, baiting, and economic modeling is needed.

REFERENCE #: G012

Harrington, David. 1992. A sea grant perspective on reducing by-catch. *In* International Conference on Shrimp Bycatch, Southeastern Fisheries Association, Tallahassee, Florida, May 24-27, pp.65-82.

Gear operation and construction

The author reviews different types of Turtle Excluder Devices (TEDs) used in the southeastern shrimp fishery, detailing the efficiency of each and features which affect bycatch exclusion rates. The author also explores options for utilizing by-catch through ethnic market development.

"There are basically two types of TEDS, soft and hard. All hard TEDs today are bottom-shooters and made of grids....the majority of these are versions of the Georgia Jumper (Figure 1a). Of the soft TEDs, only the Morrisson (Figures 1b &2) is in wide use. There are two types of soft TEDs, bottom excluders and top excluders.....Compared to soft excluders, hard TEDs are more mechanical. The behavior of different species also affects exclusion rates in different TED types....Assuming proper installation, the factors most affecting by-catch exclusion in hard TEDs are bar spacing, funnel use or non use, and flap arrangement; in soft TEDs the major factors are mesh size, flap use or non use and exclusion point, i.e., top or bottom."

TEDs are considered Bycatch Reduction Devices (BRDs) when modified or combined with a trawl feature. The following designs are described based on fishermens' observations: Short Bag/Georgia TED, Snake Eyes, Low Profile Trawls, Fish Eyes, and Modified Morrison. Figures are shown for each.

Selectivity

Figures are shown for the Georgia, Morrison, Lettich, Andrew 4-panel, Andrew 3-panel, and Golden TEDs, with exclusion rates listed for each. The least finfish exclusion (11%) was obtained with a Georgia TED when the widest bar spacing was combined with a funnel. Bottom shooting soft TEDs showed the highest exclusion rates, the Golden TED with 6 inch string mesh showing the greatest.

Finally, product development of bycatch is discussed, and planned BRD work in the future listed.

REFERENCE #: G013

Gray, C.A., V.C. McDonall and D.D. Reid. 1990. By-catch from prawn trawling in the Hawkesbury River, New South Wales: species composition, distribution and abundance. *Aust. J. Mar. Freshwater. Res*., **41**, 13-26.

Selectivity

Researchers examined seasonal and area differences in the composition, distribution and abundance of by-catch from prawn trawling in the Hawkesbury River, New South Wales. In addition, they measured possible differences in the fauna between sections of the river upstream which were open and closed to prawn trawling. The purpose of the study was to assess the degree to which trawling impacts fauna in the estuaries, a nursery area for juveniles of commercially and recreationally important species of fish.

An otter trawl was used to sample 3 areas of the river, divided by varying levels of salinity, for 2 years between March 1986 and February 1988. Areas 1, 2, and 3 were 0-25, 25-60, and 60-80 km from the mouth of the river, respectively. Seventy-five species of fish, 13 species of crustaceans, and 5 species of molluscs (listed in paper) were caught as by-catch, 42 of which were either commercially or recreationally important.

By-catch differed among the 3 areas and was generally composed of small individuals. Most of the by-catch was caught closest to the mouth, and least upstream. In all areas more species were caught in autumn and winter than in spring and summer for both years, and overall, more species caught in 1987 than in 1986. In the area furthest upstream, there were no differences in the number of species caught in sections open and closed to trawling. This assessment is not conclusive, however, since the areas sampled had been trawled previously. Control areas must be sampled at the same time to properly determine the effects of trawling on the faunal populations.

REFERENCE #: G014

Rulifson, Roger A., James D. Murray, and James J. Bahen. 1992. Finfish catch reduction in south Atlantic shrimp trawls using three designs of by-catch reduction devices. *Fisheries* 17(1): 9-20.

Management issues

In the southeastern U.S. shrimp fishery, turtles, crustaceans, invertebrates, and juveniles and adults of several finfish species are caught incidentally in otter trawls, an unselective type of fishing gear. In the 1980s the southeastern commercial shrimp industry began using Turtle Excluder Devices (TEDs) to reduce the incidental catch of sea turtles. These devices, however, are thought to reduce shrimp catch. Moreover, regulatory specifications developed by the National Marine Fisheries Service for TEDs do not address the issue of finfish by-catch.

Gear construction and operation

Three by-catch reduction devices (BRDs) were designed and tested for use in standard shrimp trawls in the Gulf and South Atlantic regions. The devices were designed to try and reduce the by-catch of commercial shrimpers while improving the efficiency of operation and quality of the catch.

The square-mesh BRD, the diamond-mesh BRD, and a modified Parrish TED were compared. Descriptions and illustrations of each device are included in the paper. Full-scale BRDs were mounted in standard paired shrimp trawls and towed in coastal waters off south Georgia, USA. One BRD design was sewn in front of the tailbag of either the port or starboard net while the other trawl served as a control. For each tow, total biomass, shrimp weight, and total number of brown and white shrimp were recorded.

Selectivity

The modified Parrish TED was the only BRD that had a significant reduction in the percent difference in total biomass compared to the control. The square-mesh net, diamond-mesh net with hoops and without hoops, and the normal Parrish TED did not reduce total biomass significantly. Three BRD designs had significant changes in percent difference in shrimp weight compared to controls: the normal Parrish TED had an increase in shrimp weight, and the modified Parrish TED and the diamond-mesh net with hoops had a decrease in shrimp weight. The normal Parrish TED was best suited for escapement of smallest menhaden, while the diamond-mesh BRD with hoops best minimized capture of the smallest Atlantic bumper, grey trout, and Atlantic croaker. The square-mesh net was most effective in reducing retention of smallest-sized thread herring, and the modified Parrish TED retained less of the smallest-sized spot.

Statistical analyses of the data were hampered by several problems in the experimental design. Nevertheless, results from the study suggest that BRDs can be effective in reducing juvenile by-catch while simultaneously allowing the capture of marketable fish, that the gear shows promise for reaching the objective of a 50% by-catch reduction in South Atlantic waters, and that not one BRD design will be ideal for all species and all fishing conditions.

REFERENCE #: G015

Watson, John W. 1992. Status of knowledge in the United States relating fish behavior to the reduction of bycatch. *In* International Conference on Shrimp Bycatch, Southeastern Fisheries Association, Tallahassee, Florida, May 24-27, 1992. pp.185-197.

Gear design and operation

This paper examines the effectiveness of a trawl modified to alter water flow within the trawl as a means to reduce finfish bycatch. Authors present observations and interpretations of fish behavior, specifically red snapper, in shrimp gear and fish responses to trawl modifications.

Many fish respond to visual stimuli in the trawl, orienting to part of the gear and attempting to keep pace with it. In these cases a fish must be able to sustain a swimming speed equal to the relative flow within the trawl, to escape if there is a proper opening. Some fish do not have visual sensitivity and depend more on sensory systems such as touch and smell.

Red snapper were observed to respond to changes in water flow direction caused by the turbulent flow around the trawl and to objects within the trawl. Gear was modified to try and create areas of reduced flow which would allow fish to swim without becoming exhausted. A funnel of webbing in combination with large mesh openings, and a modified fish excluder were tested, both of which change the water flow characteristics. Small diameter wires attached to a frame which emit low frequency sounds and tactile stimuli to stop fish passage into the codend is also being considered. Figures are provided for all techniques.

"Fish were observed to respond to changes in water flow characteristics and accumulate in the slower water flow...Escapement of fish through the openings occurred for most species during haulback. Fish which exhibit optomotor (visual) response remained in the trawl even when they were in close proximity to escape openings. Fish which did not exhibit an optomotor response exited the trawl through the openings during the tow and exclusion rates for these species approached 100%. The 'hummer wire' deflector improved fish exclusion for species which exhibited an optomotor response.

Data from initial comparative fishing trials with modified trawls indicated the fish excluder modifications reduced the bycatch of juvenile red snapper which were larger than 100 mm in length. Snapper smaller than 100 mm in length were apparently unable to escape."

REFERENCE #: G016

Boddeke, Rudolph P. 1992. Bycatch reduction of penaeid shrimp trawlers on basis of European experiences. *In* International Conference on Shrimp Bycatch, Southeastern Fisheries Association, Tallahassee, Florida, May 24-27, 1992. pp.229-244.

Selectivity

In this paper the author considers behavioral and anatomical characteristics of fish and shrimp in finding an adequate method to avoid by-catch of fish in penaeid shrimp fishing. Fleeing responses to visual and tactile stimuli, and activity patterns in general, are species-specific. Reducing by-catch through selective methods is difficult since the same boats fish different depths, at different times of the day, for separate species. Moreover, adult penaeid shrimp are not much smaller than many benthic fish species in tropical seas.

Different types of gear and their selectivity are described for separate species. A shrimp beam trawl developed in the Netherlands avoids the bycatch of flatfish in the fishing for tiny brown shrimp *(Crangon crangon)*. The effect of the trawl depends upon the difference in behavior and size between small shrimps and larger flatfish.

Horizontal separator panels in otter trawls are effective in separating certain fish species in the fishery for the Norwegian lobster (*Nephrops norvegicus*). With this technique legal-sized haddock, whiting, and hake can be separated into the upper compartment with the lobsters retained in the bottom.

A low ottertrawl is effective for the catch of bottom-bound species like shrimp, Norwegian lobster, flatfish, and cod but ineffective for the catch of more pelagic species. This is due to the gear’s rigging components, the visibility and orientation of the headline, and the trawling speed of the boat.

To minimize the catch of larger demersal species as well as turtles it is best to use a “Dutch type separator” which allows animals to escape through a hole in the belly of the net in front of the selective panel.

Undesirable bycatch of certain fish in trawls for bottom-bound crustaceans can be reduced by lowering the height of the trawl. Furthermore, if hauls can be shortened till one hour or less, sorting devices developed in the Netherlands would become practical.

REFERENCE #: G017

Bullis Jr., Harvey R., and Hilton Floyd. 1972 Double-rig twin shrimp-trawling gear used in Gulf of Mexico. Marine Fisheries Review. 34 (11-12): 26-31.

Gear construction and operation

A double-rig shrimp trawl fished along the Texas coast is described. In twin trawling two trawls are towed from each outrigger instead of one. The two trawls are joined at the head rope and foot rope to a "neutral" door connected to a third bridle leg.

Rig specifications for a Texas fishing boat are detailed. Reported advantages of the twin rig include increased fishing efficiency, ease of handling two 35 foot trawls compared to a single 70 foot trawl, smaller trawl doors needed, and as a result, less horsepower used for towing. There have been no sustained comparative tests to prove these advantages.

A "traveling out-rigger block" used aboard U.S. shrimp trawlers is also described. This block moves the trawl door from the tip of the outrigger boom to the vessel to facilitate access to the lazy line and hoisting of the cod end. Pictures and diagrams are included.

REFERENCE #: G018

Changchen Y., Li Peijun, and Ma Ying. 1992. Harvesting the Chinese shrimp by non-trawling methods with no bycath. *In* International Conference on Shrimp Bycatch, Southeastern Fisheries Association, Tallahassee, Florida, May 24-27, 1992. pp.199-214.

Management issues

Since the late 80's, the trawl method to harvest shrimp in China's Pohai Sea has been prohibited due to the large amount of by-catch generated. The by-catch, composed of mainly juvenile fish, was four to eight times the shrimp catch. Instead, a shrimp drift net developed in the early 70's has been in use which minimizes by-catch.

A stock enhancement project is also described. To rebuild the shrimp fishery which had collapsed in the Northern Yellow Sea, 160 million young shrimp were released in 1985 and yielded 950 tons that year. Since then, releases have been carried out regularly and have been profitable to fishermen. A similar project in the Pohai Sea was not as successful.

Gear construction and operation

Authors describe the shrimp drift net in regards to gear structure, fishing method, and fishing power. The net is a kind of gill net made of single pieces of net and left to drift in the sea. Length and mesh size of the net are suited to the fishing operation. Fishing efficiency increased from 1978 to 1985 due to the lower cost of a shrimp net relative to a trawl, and improved operative skill of drift net fishermen. By 1985 the fishing power of the drift net was about 25 percent of a pair of trawling boats.

"As a result of this increased economic efficiency, the total fishing mortality for the Chinese shrimp fishery in Autumn in the Pohai Sea did not decrease, but increased and surpassed the historical level."

<u>REFERENCE #:</u> G019

Chavez, Ernesto A. 1992. The suripera, an option to minimize shrimp by-catch. *In* International Conference on Shrimp Bycatch, Southeastern Fisheries Association, Tallahassee, Florida, May 24-27, 1992. pp.143-152.

<u>Gear construction and operation</u>

In the state of Sinaloa in Northwestern Mexico, the tapo and castnet are commonly used to catch shrimp inshore, where the use of the otter trawl is illegal. In the early 80's, shrimp fishermen in the Sea of Cortez's coastal lagoons developed the suripera net, a series of 2 up to 10 castnets attached to each other side by side. According to this preliminary report, the net is more efficient in shrimp catch, can be operated at low cost, and minimizes unwanted by-catch.

The suripera net is composed of approximately two or three bags and cod-ends, monofilament net with a mesh size of 30 mm, and height from two to five meters (diagram shown). The reins of the net are pulled from the ends by a seven-meter long beam. The net is used best within strong currents at tide channels deeper than 2 meters.

"The suriperas are about three times more efficient than castnets, catching more shrimp with less fuel consumption than castnets and the bycatch amounts to only 10% of total catch as compared to about 50% taken by castnets."

The results reported in this paper are not conclusive.

<u>REFERENCE #:</u> G020

Garcia, Adolfo. 1995. Impact of artisanal fishery of production of the pink shrimp *Penaeus Farfantepenaeus duorarum* Burkenroad, 1939. *Ciencias Marianas*, 21(3): 343-359.

<u>Habitat/Ecological impact</u>

Declines in the catches of pink shrimp in the southwest region of the Gulf of Mexico has been attributed, in part, to the expansion of the artisanal fishery. The fishery started out on a small scale though increased greatly during the 1980's due to a high consumer demand for juvenile shrimp. Growth of the artisanal fishery has been a source of conflict due to repercussions effecting the industrial fishery. In this paper the level of impact on the population and production of shrimp are analyzed using simulation models.

Simulations of the interaction between artisanal estuarine and industrial marine fisheries were made based on a yield per recruit model. Growth and mortality rate parameters for the model were taken mainly from the literature.

“The artisanal fishery of pink shrimp causes a decrease in the offshore production of the shrimp, since it occurs in the stage prior to recruitment and affects its levels. Impact is directly proportional to the intensity of exploitation during the estuarine stage in the coastal zone.”

“According to the simulations, using the natural mortality rates......., an effort equivalent to obtaining 120 t per year of pink shrimp juveniles can cause an impact of a 10 to 20% decrease in the offshore catch......”

“An average biomass is lost equivalent to 9 kg for each kilogram extracted from the nursery area. In terms of catch value, the difference is even greater since each kilogram of juvenile shrimp...would reach a value between 23 and 32 times greater with the average fishery mortality pattern used offshore.”

<u>REFERENCE #:</u> G021

Hannah, Robert W., and Stephen A. Jones. 1991. Fishery-induced changes in the population structure of pink shrimp *Pandalus jordani*. *Fishery Bulletin*, **89**:41-51.

<u>Habitat/Ecological impact</u>

Possible changes in the population structure of ocean pink shrimp were measured to assess the impact of the Pacific trawl fishery. The Pacific trawl fishery has increased its landings from approximately 220 mt in the early 1960s to over 18,000 mt in the 1980s. Evidence of changes in the shrimp population structure was identified previously in 1984, and fishing effort and catch has increased since then.

Growth, age, and sex composition were analyzed from catch sampling data from 1968-88. Specifically, researchers looked for shifts in age and sex composition, changes in the age of female maturity, evidence of reduced stock biomass, and improved shrimp growth as a response to lower biomass.

They found significantly greater carapace lengths of age-1 and age-2 pink shrimp for the 1979-1988 period compared with the 1966-78 period. This also corresponded with an increase in mean weight at age. "Since age-2 shrimp are fully recruited to the trawl gear, this result rules out any apparent increase in length due to fishery or gear selectivity."

In terms of age composition, age-3 shrimp decreased from the 1966-78 to 1979-88 samples, while age-1 shrimp increased. "The increases in relative abundance of age-1 shrimp may be explained in part by the fact that they are recruited to the trawl gear earlier in the season due to increased size at age in recent years."

The decline in numbers of older shrimp has coincided with an increase in the percentage of shrimp maturing directly into females at age-1. Though younger shrimp comprise most of the population, this is compensated for by a greater number of primary females, resulting in the maintenance of a sexually balanced breeding population.

Results support the conclusion that pink shrimp are exhibiting density-dependent growth, and that changes in growth, age, and sex composition of the catch are due in part to the impact of the trawl fishery. Though these changes allow the population to withstand over-harvest, "at some level of exploitation, accelerated sex change and density-dependent growth will not prevent declines in larval release and subsequent recruitment."

<u>REFERENCE #:</u> G022

Harris, A.N., and I.R. Poiner. 1990. By-catch of the prawn fishery of Torres Strait; composition and partitioning of the discards into components that float or sink. Aust. J. Mar. Freshwater Res., **41**, 37-52.

<u>Habitat impact</u>

Floating and sinking components of bycatch are distinguished from commercial prawn trawling catches in Torres Strait, Australia. The purpose of sorting the catch into these components is to evaluate the type and quantity of food potentially available to surface and demersal predators.

The catches of 31 trawls in 1988 were used to estimate the proportion of catch that floated or sank. Ninety-eight percent of the non-teleost bycatch sank, and the remaining 2% which floated were mainly cephalopods. About 60% of the teleost catch sank and were mainly benthic species.

Floating in fish depends upon the position and anatomy of the gas bladder, and on the ability of the blood to resorb gas from the gas bladder. A fish will float if it cannot either resorb or release gas properly with depth, and if its gas bladder is not ruptured.

The rate at which the trawl net is hauled at the end of a trawl shot, and the depth at which the trawl net is fished can affect the floating characteristics of the fish catch. In this study, the floating characteristics of 6 fish families tested showed a significant difference between deeper and shallower trawls.

“Apart from nutrient regeneration as a stimulus for increased primary production, the ecological consequences of such practices remain largely unknown. Predators and scavengers may be advantaged by having access to a food source requiring little hunting or scavenging effort, but for bottom-dwelling animals this has to be balanced against a higher risk of mortality due to prawn trawling.”

REFERENCE #: G023

Hein, Stephen, and Paul Meier. 1995. Skimmers: their development and use in coastal Louisiana. *Mar. Fish. Rev.* **57**(1). pp. 17-24.

Gear construction and operation

A description and use of the skimmer net used in coastal Louisiana is presented. According to shrimpers, the primary reason for the development of the net in 1983 was to catch white shrimp, commonly observed jumping over the cork line of trawls. The skimmer net frame allows the net to be elevated above the water while the net is fishing, thus preventing shrimp from jumping over the top. In 1994, the skimmer net was the second most common shrimping gear, after the otter trawl, used in Louisiana.

Skimmers most closely resemble butterfly nets. They are operated in the same manner and subjected to similar legal restrictions. The basic components of the skimmer gear include net frames, nets, heavy weights, skids, winches, and tickler chains. Different types of fish excluder devices are used by some fishermen to reduce bycatch. Illustrations and a detailed gear description are provided.

Some advantages of the skimmer net include: multiple use as both trawl and butterfly net (if weight is added to the bullet), ease of deployment, continuous fishing capability after the cod ends are emptied, reduced bycatch, and better survivability of nontarget organisms. Some disadvantages include: being limited to the depth fished by the 12 foot deep outer leg, and bottom damage caused by improperly tuned gear.

In a 1993 comparative study with otter trawls during the white shrimp season, bycatch was about 30% less with the skimmers. The fish to shrimp ratio was about 1:1 for skimmers and 8:1 for otter trawls. Skimmers outfished otter trawls by 5:1.

Management issues

The skimmer net has become one of the most efficient shrimping methods in areas of Louisiana where marshes have subsided and shorelines eroded. Some fishermen oppose its use because of potential water bottom damage and destruction of juvenile shrimp, though still use it due to the competitive industry. Though there are numerous advantages to the gear over the conventional methods, skimmers may not be promoted in a management regime due to their perceived overexploitation from such efficiency.

REFERENCE #: G024

Hutchings, Pat. 1990. Review of the effects of trawling on macrobenthic epifaunal communities. *Aust. J. Mar. Freshwater Res*. **41**, 111-20.

This review summarizes trawling activties and gear used in three areas of Australia, existing information on the ecology of benthic communities in the region, and the impacts of trawling on these communities.

Gear construction and operation

Pair trawls are used on the North West Shelf, where a net is towed between two trawlers and a tickler chain is dragged over the bottom in front of the net. Since this disturbs epifaunal communities (animals attached or crawling on the bottom), a trap fishery has recently developed in order to reduce the impact.

In the northern prawn fishery the type of trawling activity is determined by the target species. A net with a small opening and towed 15 cm off the bottom is used to catch tiger prawns and other species; rigged in this manner the catch of epibenthic fauna is reduced.

Habitat impact

Trawling removes or damages the macro-epibenthic fauna. Small colonies may not be able to sustain repeated trawls. The dead fauna that is discarded becomes available as food to benthic scavengers such as crabs, or to dolphins and birds should the discards float.

One study reported substantial catches of sponges in the early years of the pair trawl fishery (pre-1972 research surveys), and a significant reduction by 1979. Loss of these sponges has led to the reduction in catches of species of *Lethrinus* and *Lutjanus*. A researcher in Torres Strait noted that mainly sponges were caught in trawled areas, whereas untrawled areas supported much more diverse communities. A study conducted on the North West Shelf showed that the biomass of epifaunal organisms had dropped dramatically with trawling and changed the dominant species of fish caught.

Management issues

"No studies have measured the rates at which epifaunal benthic communities recover after trawling. The paucity of data on recruitment and growth of constituents of the epifaunal communities is such that no estimates can even be made of the time required. Factors such as the size of the trawling ground, the distance from nearby untrawled areas from where larval recruitment may occur, the type and frequency of trawling undertaken, and the time of year when fishing occurs, all need to be considered in any management options."

REFERENCE #: G025

Gray, C.A., V.C. McDonall and D.D. Reid. 1990. By-catch from prawn trawling in the Hawkesbury River, New South Wales: species composition, distribution and abundance. *Aust. J. Mar. Freshwater. Res*., **41**, 13-26.

Selectivity

Researchers examined seasonal and area differences in the composition, distribution and abundance of by-catch from prawn trawling in the Hawkesbury River, New South Wales. In addition, they measured possible differences in the fauna between sections of the river upstream which were open and closed to prawn trawling. The purpose of the study was to assess the degree to which trawling impacts fauna in the estuaries, a nursery area for juveniles of commercially and recreationally important species of fish.

An otter trawl was used to sample 3 areas of the river, divided by varying levels of salinity, for 2 years between March 1986 and February 1988. Areas 1, 2, and 3 were 0-25, 25-60, and 60-80 km from the mouth of the river, respectively. Seventy-five species of fish, 13 species of crustaceans, and 5 species of molluscs (listed in paper) were caught as by-catch, 42 of which were either commercially or recreationally important.

By-catch differed among the 3 areas and was generally composed of small individuals. Most of the by-catch was caught closest to the mouth, and least upstream. In all areas more species were caught in autumn and winter than in spring and summer for both years, and overall, more species caught in 1987 than in 1986. In the area furthest upstream, there were no differences in the number of species caught in sections open and closed to trawling. This assessment is not conclusive, however, since the areas sampled had been trawled previously. Control areas must be sampled at the same time to properly determine the effects of trawling on the faunal populations.

REFERENCE #: G026

Perret, William S., and Philip E. Bowman. 1992. Butterfly and skimmer nets in the Gulf of Mexico and their potential use elsewhere. *In* International Conference on Shrimp Bycatch, Southeastern Fisheries Association, Tallahassee, Florida, May 24-27, 1992. pp. 325-333.

Authors review the history of the Louisiana shrimp fishery in regards to the types of gear used and economic value. Pros and cons of bycatch are addressed, and specific attention given to levels of bycatch in skimmer and butterfly nets.

Gear construction and operation

The butterfly net attaches to a rigid frame and is arranged so the cod end can be emptied on the deck of the boat without interrupting fishing. Fishing primarily takes place at night in the upper portion of the water column.

A skimmer net is like a cross between a trawl and butterfly net. It is attached on two sides to a triangular frame and suspended from the sides of a boat, with one corner on the boat and the other resting on the water bottom. It is suited for shallow coastal bays and can be employed during day and night.

Selectivity

One study showed that bycatch mortality was lower in a butterfly net than in a trawl. Survival of the bycatch was enhanced since the nets were emptied more frequently and the water and air temperatures were cooler.

Preliminary investigations of the skimmer nets showed that these nets were more effective at harvesting shrimp while allowing unwanted animals to be released. Bycatch could be returned to the water in better condition since the nets were emptied more frequently.

REFERENCE #: G027

Schick, Daniel F. 1992. Fishing with traps for pandalid shrimps/Bycatch reduction with large mesh panels. *In* International Conference on Shrimp Bycatch, Southeastern Fisheries Association, Tallahassee, Florida, May 24-27, 1992. pp. 245-278.

History and statistics (Traps)

Fishermen operate traps mainly in the mid-coast region of Maine for 8-10 weeks per year. Traps are rectangular with vinyl coated steel wire mesh and top entrances, baited with either herring or mackerel. Bycatch consists of two other species of Pandalid shrimp. Trap fishing conflicts with the otter trawl fishery, though trapping is possible due to the existence of many narrow, deep mud-bottom channels that shrimp will migrate into and that cannot be dragged. Trapping of shrimp is directed at the females as they arrive inshore during larval release. In the 1980s, the percent of trapped shrimp was highest for the years that each year class came inshore as second year females (the 1987 fishery for the 1982 year class, and the 1992 fishery for the 1987 year class).

Gear construction and operation

To reduce bycatch in otter trawls several gear designs were tested: large mesh panels, radial escape sections, skylight panels in the extension, diamond shaped flapper in the extension, and triple poly flappers. Figures are shown for each.

Large mesh panels - A regular shrimp net modified with 6" mesh hung behind the footrope and a diamond escape hole cut into the top of the extension was compared with a control net. The mean total catch was reduced with the modified net by 15.7%. The mean shrimp catch was reduced 10.2%. The roundfish category showed an overall loss of 17% by weight while the flatfish category showed an overall gain of 8%. A combination net, rigged on one side with a large mesh panel and poly flapper and the other side serving as a control, was also tested. The experimental side caught an average of 25% less fish by weight than the control.
Radial escape section - The radial escape section is a modification to the extension of the net where the back end of the belly is narrowed into a funnel and a second funnel is suspended behind it. This net caught 66% less total catch than the control net.
Skylight with deflector - A rectangular opening skylight in the top of the extension with a deflector panel sewn in front was tested. The catch in numbers and weight per species showed no difference from the control tows. A square mesh funnel in front of the skylight was also tested. This gear showed a loss of shrimp and whiting, but no appreciable loss of other finfish.
Double diamond escape hole and deflector - Two diamond escape holes cut in the top of the extension piece was tested. There was little difference in catch between the test and control tows, though when the holes were enlarged there was a drop in finfish and shrimp.
Triple poly flappers - An otter trawl with three escape holes in the top of the extension was tested. Shrimp loss was 19% by weight, hakes showed no difference, and dabs showed a gain of 55% by weight.

REFERENCE #: G028

Sheridan, Peter F., Joan A. Browder, and Joseph E. Powers. 1984. Ecological interactions between penaeid shrimp and bottomfish assemblages. *In* Penaeid Shrimps - Their Biology and Management, Fishing News Books Limited, Farnham, 1984. pp. 235-254.

Habitat impact

Authors review ecological interactions between commercial penaeid shrimp and bottomfish, and describe two models used to evaluate the impact of the fishery on shrimp stocks. Bottomfish in the study share the same habitat with shrimp and are caught with shrimp in trawls, then returned to the sea as carrion. Predation, competition, or scavenging are assumed to exist between the two stocks exploited by a common fishery. The first model treats the problem as one of two stocks each partially supported by the discards of the other. The second model treats the problem as one of 11 trophic elements linked by the flow of energy and the cycling of nitrogen.

The "discard model" addresses the impact of discarded shrimp and bottom fish on the populations' productivity. This model suggested that discards most favorable to shrimp would increase shrimp harvests 8% compared to no discards. "Since assimilation rates in the model were deliberately overestimated, the actual benefit of discards to shrimp production is probably less." Environmental influences causing variation in year class strength make the detection of assimilation with fisheries data difficult.

The "energy-flow ecosystem model"assumes that species stocks in the system are resource limited. Important points about the food web diagram shown are that: reducing discards minimizes food available to shrimp, and bottomfish can interfere with shrimp stocks through both predation and competition. The model suggests that, "theoretically, shrimp biomass would decline 25% if discards were reduced by utilization of one half the by-catch, but would decline by only 8% if discards were reduced through the use of new trawls one-half as efficient in catching fish." The 8% reduction occurred if bottomfish preyed only upon shrimp. If bottomfish preyed upon alternative species, "the introduction of special trawls would result in no long term effect on shrimp stocks and shrimp harvests."

REFERENCE #: G029

Silas, E.G., and M.J. George, and T. Jacob. 1984. A review of shrimp fisheries of India: a scientific basis for the management of the resources. *In* Penaeid Shrimps - Their Biology and Management, Fishing News Books Limited, Farnham, 1984. pp. 83-103.

Management issues

Mechanization of India's shrimp fishing craft and boats, and the entry of large business houses into the fishery, have put pressure on existing stocks along the coastline. While these activities once placed India as the top shrimp producer in the world around 1973, shrimp production has been declining since then. The multi-species nature of the fishery, in which a wide variety of craft and gear are used, makes proper management and conservation efforts difficult. "The management objectives with which the problems are approached in this country has been oriented towards higher production and maximum development of the resources."

This paper reviews the problem of managing India's fishery resources, with discussion of the artisanal and industrial fishing practices, bycatch, environmental aspects, and management techniques. Fishery closures, mesh regulation, limitation of fishing effort, catch restrictions, diversification, and habitat protection are discussed as management options.

Gear construction and operation

Some fishermen continue to operate traditional crafts such as catamarans, canoes, and plank-built boats, while mechanized crafts are slowly replacing the indigenous sector in several areas. Indigenous gears are still used in addition to otter trawl nets, the more popular and effective fishing method. Fixed nets, seine nets, cast nets, scoop nets, drift nets, and trawl nets are described.

A considerable amount of bycatch from trawling and indigenous practices is landed. "In the total landings of 398,945 tonnes in 1979 by smaller shrimp trawlers the fish and other miscellaneous bycatches apart from shrimp amounted to 315,902 tonnes forming 79.18% of the total." A demersal fishery of very high magnitude exists in the country. Other species besides bottomfish which are caught in high numbers are sharks, jewfishes, and silver bellies.

Habitat impact

Fluctuations in shrimp landings are attributed to natural variations, such as monsoons, rainfall, and phases of the moon, and also to human activities, such as the destruction of mangroves, diversion of water flows, and underwater mineral extraction. "In general the estuarine habits are affected in two major ways, either by net loss of total acreage available or by a change in mean salt content and chemical composition."

REFERENCE #: G030

Wassenberg, T.J., and B.J. Hill. 1987. Feeding by the sand crab *Portunus pelagicus* on material discarded from prawn trawlers in Moreton Bay, Australia. *Marine Biology* **95**, 387-393.

Habitat impact

A study on the feeding habits of sand crab in relation to discards from prawn trawlers in Moreton Bay, Queensland, is presented. A fishery for the sand crab employing 50 full time fishermen operates in the same area as the otter trawl prawn fishery.

Information was collected on the crabs' prey items, the rate of uptake and clearance of food, feeding behavior in the laboratory, and in the field using underwater photography. Mainly, animals discarded from trawls constituted about 33% of the crabs' diet. Fish and prawns were higher in number and weight in the foreguts of crabs captured while trawling was occurring than when not. The undigested appearance of the material and rapid clearance of food indicate that the fish and prawns had been recently ingested. In photographs taken of the trawl grounds, scavengers were only present in baited (vs. non-baited) exposures, and the sand crab was the most frequently observed scavenger.

In Australian waters the sand crab extrudes its eggs between September and April, which coincides with the prawn trawling season. Other evidence has shown that an increased food supply to the crab nearly doubles the percentage of ovigerous females. "It is possible that the food available to the sand crab from prawn trawlers in Moreton Bay may enable higher population densities of these crabs to be maintained than there would be without trawling."

<u>REFERENCE #:</u> G031

Whitaker, David J., Lawrence B. DeLancey, and James E. Jenkins. 1992. Shrimp "baitfishing" in South Carolina and preliminary notes on bycatch research. *In* International Conference on Shrimp Bycatch, Southeastern Fisheries Association, Tallahassee, Florida, May 24-27, 1992. pp.215-228.

<u>History and Statistics</u>

This paper reviews the history and growth of the white shrimp fishery in South Carolina and the studies that have been conducted on the effectiveness of shrimp baiting. Some research is presented on finfish by-catch reduction using hand seines and a Florida Finfish Excluder.

A recreational fishery for white shrimp operates in the peripheral waters of estuaries largely at night from 1 September to 15 November. Fishermen use a mixture of mud and fish meal to attract shrimp which are then caught with cast nets. Authors detail how the shrimp are harvested, laws and regulations concerning the fishery, and catch trends. In addition they review studies on the effectiveness of shrimp baiting versus non baiting, size of shrimp caught by area, and catch rates and size of shrimp caught with different mesh sizes.

<u>Selectivity</u>

The fishing method is relatively efficient with little by-catch. The total combined by-catch in two studies using bait was 57 fish in 540 casts. Most fish can be returned to the waters alive. "From a resource management standpoint, finfish by-catch per unit of shrimp harvested appears much less than that of traditional casting methods or shrimp seining."

A pilot study was conducted to examine the potential for reducing by-catch in a shrimp trawl. Comparisons were made between a control net and a net rigged with two Florida Finfish Excluders. The experimental gear released 39% of the weakfish, 68% of the flounder, and 49% of the croaker, and were most effective in excluding fish 12-13 cm in length. No loss of shrimp occurred with the experimental gear.