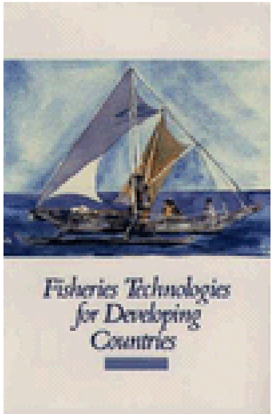

Fisheries Technologies for Developing Countries

Board on Science and Technology for International Development, National Research Council

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Preface

The future of traditional fisheries will be shaped by the attention given to their special problems and by the recognition of their unique value. Declining stocks of readily accessible fish, competition from industrial fishermen, high operating costs, less than optimal gear and vessels, poor storage and marketing facilities, and little access to credit all tend to limit development for fishermen in the traditional sector. Culturally and economically acceptable technologies can help with some of these problems, but policy changes and interventions must also be part of the assistance strategy.

The effort is worthwhile. Traditional fishermen are important contributors to the food supply in developing countries. They currently account for about one-quarter of the world's total fish catch-an estimated 20 million tons of a total of 80 million. Although only about one-fifth of the fish caught in Latin America come from the traditional sector, in Asia these fishermen provide two-thirds of the catch, and in Africa, five-sixths.

Traditional fishermen are economically important for other reasons as well: their boats and gear are locally produced, easily repaired with local parts, and represent a low capital investment; their fish-capture techniques and propulsion methods are both low energy consumers. Commercial fishing boats and gear, in contrast, are largely imported, and therefore often require imported spare parts. Moreover, they require a high capital investment and consume large amounts of energy to reach and capture fish. There is also more wastage of by-catch from their operations.

Many developing countries have ignored traditional fishermen and have concentrated their assistance in industrial fisheries. Traditional fishermen have suffered more than neglect from this policy: commercial trawlers operating near shore can simultaneously harvest large numbers of fish (including juveniles) and destroy spawning and breeding grounds. The adverse effects for the traditional fishermen are both immediate and persistent; current stocks are depleted and the potential for recovery is reduced.

Developing countries could increase their fish harvest and improve the quality of life for their coastal dwellers by providing traditional fishing communities with access to modest technical and financial resources and by assuring protection for their fishing grounds. The evaluation and introduction of some of the technologies described in this report could initiate this process.

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Information in this report was largely derived through a meeting (participants listed on pages iii-iv) at the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences in Miami, Florida, August 13-15, 1985. Additional data was obtained through correspondence with fisheries experts throughout the world.

Contents

Overview

Many of the fishermen in developing countries are locked into economic systems that result in relative poverty. Although the technologies they use have evolved in accord with indigenous biological resources and socioeconomic realities, there may be opportunities for improvement. Existing technologies from other developing regions might be transferred to these fisheries and some of the technological advances from industrialized countries might benefit artisanal fishermen.

This report describes some of these innovative fishing technologies for small-scale fishermen, administrators of fisheries, development assistance groups, and others concerned with fisheries. The objective is to establish new contacts, to examine alternative fishing technologies, and, after careful planning, to encourage application in new areas.

SMALL-SCALE FISHERMEN

There are about 15 million traditional small-scale fishermen in the Third World, perhaps half of whom fish full time. Another 15 million people are involved in fish preservation and distribution. Assuming an average family of six, close to 200 million people in poorer countries are dependent on small-scale fisheries. For these people and the many others whom they supply, fish caught by traditional methods represent their principal source of protein.

Traditional fisheries may be commercial or subsistence, but they each have in common a small cash income. Fishermen of this sector often live in isolated coastal villages and may also be engaged in subsistence agriculture. In many societies, artisanal fishermen occupy the lowest social and economic class.

The fisherman's main wealth is in his fishing gear (boats, motors, nets, and lines), which is subject to rapid depreciation and loss. Fishermen either construct their own boats and assemble their gear or purchase them from village experts. In some cases, their small boats are powered with outboard gasoline motors, although sail and paddle power are common. Fishing practices tend to be labor intensive with minimal mechanical assistance. The total investment in fishing equipment is generally quite low, and the artisanal fisherman is quite adept at minimum input management.

Fishing productivity in the artisanal sector is consequently variable and low; many fishermen catch only one or two tons of fish per year. Nevertheless, the fish catch per ton of fuel consumed is much higher than in the industrial sector. The catch is rarely distributed in organized markets; more often it goes to local markets or is consumed by the fishermen's family.

PROBLEMS OF SMALL-SCALE FISHERMEN

Artisanal fishermen face a series of difficulties that contribute to their marginal standard of living. Government fishery policies often tend to concentrate resources in the modern, large-scale, commercial fisheries that earn foreign exchange. Thus, the small-scale fisherman finds it difficult or impossible to obtain credit, extension services, marketing assistance, or similar aid from development programs.

Traditional fishermen often compete with the industrial sector over limited common resources in the exclusive economic zone and commonly lose against more efficient technologies. Numerous conflicts between these two types of fisheries occur. Typically, trawlers enter areas used by artisanal fishermen, destroying spawning and feeding areas, and damaging their buoys, nets, and traps. Further, the by-catch from inshore shrimp trawlers is often discarded, both removing the resource from the small-scale effort and decreasing the availability of protein.

In many coastal zones, overexploitation of marine resources is already a serious problem that is augmented by low productivity. It heightens the conflicts between the industrial and traditional fisheries and endangers the economic and nutritional status of people who rely on the traditional fisheries.

Fish stocks may also be depleted by pollution from urban areas, industry, or mining; this more seriously affects small fishermen who have only limited mobility. Mangrove destruction, which removes vital spawning grounds, is also detrimental to coastal fish stocks.

In addition to biological overfishing and stock depletion, economic over fishing often plagues the small-scale sector. Excessive use of boats, fuel, and gear may double the effort needed to catch a limited amount of fish.

Market access is impeded by lack of credit, capital, and transportation. Moreover, the small-scale fishermen's lack of organization precludes them from influencing the market. The unavoidable dependence on middlemen for the means of production and marketing is often a great liability.

In other situations, the artisanal fisherman's reliance on less than optimal fishing vessels, methods, and gear may limit his catch, especially when he is competing with the industrial sector. The lack of adequate landing and processing facilities exacerbates heavy losses from wastage and makes selling fish outside the local area difficult.

Boat construction is a growing problem for many fishermen. The traditional dugout canoe, proa, and catamaran used for fishing and marine transportation require high-quality hardwood. With deforestation of many tropical coastal areas, these strong, workable, long-lived woods are increasingly scarce.

Many artisanal fishermen have adopted outboard motors, and sail technology has fallen into disuse. Outboard gasoline motors are expensive, difficult to repair, and not fuel efficient. Their costs can seriously restrict fishing operations. In West Africa, the lack of foreign exchange to purchase spare parts, replacement motors, and fuel has resulted in a decrease in the percentage of motorized small-scale fishing boats.

INNOVATIVE TECHNOLOGIES

While recognizing the diverse problems faced by the small-scale fisherman in the Third World, this report will primarily address technological considerations. Innovative, relatively inexpensive technologies that, under some circumstances, might help fishermen will be described. Although not necessarily the newest, most sophisticated developments, these techniques may have already found successful application in a specific region. A technology might be successfully adapted to a new area if it solves a specific problem, causes no ecological or social problems, and is economically feasible and desired by the community it is intended to serve. Successful applications of new mechanical or fabrication technologies also require training, service support, and locally available components and spare parts.

There are no universal answers in fisheries technologies. Each fishery should be studied individually to determine the technologies that are applicable to its specific conditions.

Boats

Traditional fishing vessels are highly adapted to the fishing techniques and marine conditions of a specific region. This coordination between structure and function is not without problems, however. Small fishing boats often have a limited range of operations and are unsafe. They may lack structures to store and protect the catch. The high-quality timber used for boat construction in many tropical areas is increasingly scarce. Thus, in some regions there may be a stimulus for modifications in vessel design and construction materials.

High-quality timber and planks may be replaced by laminated wood composites (plywoods) preserved and sealed with resins. Plywood pieces can be wired together with galvanized soft-iron wire and then sealed with epoxy resins in the "stitch-and-glue" technique. Plywood boats are strong and light and are used in many parts of the world.

New construction techniques use veneers or thin plywood strips to build up a laminated hull over a mold. The veneer layers are oriented diagonally to each other and glued with epoxy resins. Plywood or fast-growing woods can be used in these rapid-construction methods.

Rafts made from plastic tubes have become widely accepted in Taiwanese coastal fisheries, as have ferrocement vessels in Cuba and China.

Fiberglass is another increasingly popular material for boat construction because of its light weight, longevity, and strength. The United Nations Food and Agriculture Organization's Bay of Bengal program has adapted a fiberglass version of the traditional *oru*, a wooden outrigger. A number of fiberglass modifications of traditional West African fishing vessels have also been designed by the Yamaha Motor Company of Japan.

Alternative hull forms have gained popularity in some regions. Multihulled vessels or outriggers, traditionally found in the South Pacific and Southeast Asia, offer certain advantages for small-scale fisheries: they are stable, can be beached, and have a large working deck.

The outboard gasoline motor, widely used in small-scale fisheries throughout the world, is not very fuel efficient. Fuel is expensive, a high level of maintenance is required, and spare parts are scarce. Fishing vessels are frequently overpowered and waste fuel, in part because of the fishermen's desire for high speed to increase their range or competitiveness.

Fuel savings can be achieved by employing more efficient motors or using alternative fuels. Diesel-powered outboard and inboard motors have longer lifetimes than their gasoline counterparts and may be more economical. However, their high initial cost may be prohibitive to the small fishermen.

Gasifier technology has been developed in the Philippines and applied to fishing boats. Charcoal is burned with limited oxygen supply to produce a gaseous mixture of hydrogen, carbon monoxide, and methane, which can be used to fuel gasoline engines. Steam engines are also being investigated as power sources for small boats.

The oldest propulsion technique, wind power, is being reintroduced in a number of small-scale fisheries. Sails may be used as the main means for propulsion or to assist an engine. Fishermen can take advantage of the winds, thus saving fuel and reducing operating costs. Having an alternative propulsion source also increases the crew's safety. The details of sad-assist are specific for each fishery, since marine conditions, fishing vessels, and methods all vary.

The sails may be constructed of very inexpensive materials, such as canvas bags or the plastic sheeting used by *kattumaran* fishermen in Southern India. These sails last for many months, and can be easily repaired or replaced.

The Bay of Bengal program in India and Sri Lanka has reintroduced sailing rigs to small fishing vessels with positive results. A great deal of work has also gone into fitting sails to West African fishing canoes.

The high stability of catamarans permits them to carry larger sail areas than equivalent monohulls. Experimental fishing catamarans using sails have been adopted in India, West Africa, and the South Pacific.

Fishing Methods and Gear

The time-tested fishing methods are usually ideal for a given region since they have evolved to best fit such local requirements as the species to be captured and the desired size, the type of coast, and the marine conditions. Changing conditions may dictate new approaches, however. Modernizing factors are always a consideration for every traditional fishing method or gear. Moreover, successful fishing arts could be transferred from one region to another if conditions were comparable. There are numerous examples of innovative fishing arts being used in the Third World that are unknown several hundred miles away. New technologies could tap previously unexploited resources or allow small-scale fishermen to compete more effectively with the industrial sector.

Longlines, successfully used in many areas, offer great potential for the small-scale fishermen. These unwatched lines with multiple hooks attached to branch lines (snoods) may be set vertically or horizontally and can be anchored or allowed to drift. Modernization of this art involves the mechanization of hauling, the use of detachable snoods and polyethylene lines that float just off the bottom, and the introduction of light-emitting lures, which may help to increase the catch.

Pots and traps are universal and have the advantage of low cost and minimal inputs. They are highly specific to species and sizes, and their placement requires knowledge of the local conditions. Modernization in these fisheries is manifested by the use of more durable construction materials than traditional woods and fibers. Thus, modern Japanese octopus pots are constructed of sections of PVC pipe. Loss of traps or pots can be minimized by attaching them to longlines or by installing time release devices (pop-ups).

Light attraction of fish could be employed in many parts of the world. It is now used on Lake Tanganyika to attract fish to the opening between the two hulls of a catamaran. A liftnet captures the fish after they have been concentrated. In the Caspian Sea, light is also commonly used to attract fish to liftnets.

Trawling is a fishing technique usually restricted to industrial fisheries. However, two small boats with 5-hp motors can pair trawl, pulling the net together and thus compete with larger trawlers for benthic species.

Artificial Reefs

Fish concentrate around submerged objects such as reefs, rocks, logs, and harbor structures. Fishermen have observed this and built artificial underwater structures to concentrate fish stocks. Artificial reefs are common in many traditional fisheries. Modern technologies may provide durable materials for these structures, but their function remains the same. Artificial reefs can be used as effective management tools. By concentrating the fish crop, fishermen can save time and fuel, thereby facilitating the catch.

Bundles of brush are placed in secluded coastal areas in West Africa, Cuba, and the Philippines to provide shelter and spawning areas for fish. Lobster shelters made of mangrove branches are prevalent in the lobster fisheries of Cuba and the Yucatan in Mexico. Traditional Japanese artificial reefs employ rock and rubble to enhance fishing grounds. Tires and cement are common materials for artificial reefs in Taiwan, the United States, and Israel, whereas the Japanese invest in sophisticated fiberglass, concrete, and steel modules.

Thailand's Department of Fisheries conducts an artificial reef program whose objective is to enhance fishing grounds for artisanal fishermen. Concrete trawler exclusion modules, which damage trawling nets of industrial fisheries, have also been deployed.

Artificial reefs are placed on the sea floor; fish aggregating devices (FADS) are used at the surface or suspended in the water column to attract pelagic species. Japanese fisheries employ floating bamboo shelters to attract dolphin fish or tuna. Philippine *payaos* are tuna-attracting bamboo rafts with palm fronds that are anchored in deep water. Modem FADs are constructed of steel, plastic, and artificial fibers, and may be more durable than traditional structures. Nevertheless, they are easily lost in the marine environment.

Coastal Mariculture

Mariculture offers an alternative to the overexploited marine resources in many coastal regions. It is possible that some fishing communities could also become involved with sea farming to provide additional protein or income. Sea farming in underutilized coastal areas would not compete with terrestrial agriculture for space and could be implemented without large investments. This report will only address mariculture in the coastal ocean, not the much larger topic of pond cultivation.

Recent research by the Smithsonian Institution has shown the biological feasibility of algal turf mariculture in nearshore areas. Algal turfs are grown on screens and then fed to herbivores such as whelk, parrotfish, and crab.

Highly nutritious seaweeds are consumed in Asia and are also employed in industry. The red algae *Eucheuma* is cultured on monofilament nets on family farms in the Philippines. The edible kelp *Laminaria* is cultivated on longlines and floating rafts in China. Nori (*Porphyra*), a popular edible seaweed, is farmed on submerged nets in Japan.

Cage culture of marine fish is still in its infancy but will undoubtedly gain popularity. The cages protect the fish from predators and simplify harvesting. The limited space available to the fish ensures that they will convert feed efficiently.

Crustaceans and molluscs are widely cultured in the marine environment. Oysters, mussels, clams, and scallops are typically grown on lines, stakes, or on the bottom, in many parts of the world. The highest productivity of these animals is in off-bottom culture. Good yields of mussels have been obtained in Western Samoa. The giant clam *Tridacna* displays a rapid growth rate and has demonstrated good potential for mariculture in the Caroline Islands.

Integrated sea farms have been established in Indonesia and the Philippines. Houses are built on bamboo stilts over the protected reef fiat where sea farmers culture seaweed, shellfish, and fish.

Fish Processing

Approximately 35 percent of the world's fish catch is lost after harvesting. These losses are great in the small-scale fisheries in tropical countries. Simple preservation techniques, common in one area of the world, could be employed in others to reduce postharvest losses.

Icing is a preferred preservation technique, but since it requires gasoline or electricity, it is often expensive. The Asian Institute of Technology in Thailand has field-tested an ice-making machine that uses solar energy. Wind and biomass energy may also run refrigeration systems.

Fish may be salted by dry or wet methods, although the latter (brine and pickle) are best for tropical applications. Numerous solar driers are in use throughout the tropics. They exclude insects and develop high enough temperatures to reduce mold or bacterial spoilage. Black plastic lining in the chamber absorbs heat and initiates a flow of heated air through the drier.

Improved smokers, such as the Chorkor smoker, are gaining acceptance in West Africa. They have long lives, low construction costs, consume little firewood, and have a large fish capacity.

Other processing methods have been perfected in specific regions. Minced fish (surimi) is the starting material for a number of fishpaste products in Japan. Kamaboko—the use of cheap fish flesh for reconstituting textured marine product analogs (such as crab legs, shrimp, and lobster meat) is becoming more widespread, acceptable, and profitable. Boiling fish in water is a short-term preservation technique practiced in Southeast Asia. Fermented fish products, such as sauces and pastes, are common in South and Southeast Asia.

LIMITATIONS

This report treats fishing technology alone, as if it were isolated from biological, economic, cultural, and political considerations. The constraints of the small-scale fisherman in the Third World are usually socioeconomic and rarely due simply to the absence of a specific technology. Those who are involved in the introduction of technologies must be sensitive to the complete environment of the fisherman. Some of these interconnected considerations influencing the transfer of fishing technology include biological, economic, and social factors.

Biological Factors

Before any innovative marine technology is introduced, the marine resources to be exploited should be identified and assessed. Their temporal and spatial distribution, population dynamics, behavior, and life history should all be known. Sufficient stocks must be available to support the increased fishing effort.

At present, many coastal marine species are biologically overfished by the existing technologies. If this is the case for the fishery in question, there is certainly no need to introduce more efficient fishing technologies that would further exceed the maximum sustainable yield. A new technology will create an impact on the fish stocks. The magnitude of the impact should be determined so that effective management programs could be revised or initiated.

Economic Factors

The introduction of new technologies involves investment of capital. Artisanal fishermen will only embrace and continue to use new technologies that satisfy their own economic interests. Any increased capital, or operating or maintenance costs must be balanced by an increased catch, which translates into increased profit. Careful cost-benefit analyses, feasibility studies, and pilot projects must be undertaken to ensure that this is the case.

The new technology must also be carefully compared with and evaluated against current technologies to ascertain that it is more successful and is worth the increased investment. If it is determined that there is an overinvestment in boats, gear, and fuel (economic overfishing), it may not be wise to introduce a new technology.

Most small-scale fishermen operate with an economic philosophy of minimal input management. That is, they invest as little as possible and hope for a maximum return. This method of operation must be understood by those working in fisheries development.

Credit must be available to the artisanal fishery sector with conditions of financing that are culturally acceptable and economically reasonable for the fisherman. The specific situation would determine the most appropriate structure for extending credit and whether the primary beneficiary of the credit is the individual fisherman or a fishing cooperative.

The regional economic situation must be considered in addition to the economics of the new technology. It must be determined whether the processing and storage, transportation, and marketing infrastructure are adequate to handle an increased catch.

Social Factors

The successful introduction of technology requires a keen understanding of the cultural intricacies of a society. A technological innovation or modernization must be compatible with the existing social organization and managerial level if it is to be adopted by the community. The community's concepts of ownership of private property and tenure of the marine resources must be clearly understood by outsiders who are working in fisheries development.

The social implications of the new technology must also be carefully considered. Perhaps there will be conflict and competition with fishermen who continue to use the old technologies. Significant income disparities might be introduced into a close-knit, egalitarian community. Alternatively, social stratification could be exacerbated if only the wealthier fishermen were to benefit from the new technology. A new capital-intensive technology could also require less manpower and create unemployment. Since technology implies knowledge and knowledge translates into power, there could be significant power shifts in the community as a result of the introduction.

It must be determined if the community's social fabric is resilient enough to withstand these increased tensions or if, perhaps, the increased social stress caused by the technology would negate its benefits.

The successful acceptance of a new technology by small-scale fishermen will depend on the participation of the fishermen in the choice of technology, their belief in its economic feasibility, the manner of its introduction, the technology's demonstrated success, and its modification to meet the unique local conditions.

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1

Boat Design, Construction, and Propulsion

Traditional fishing vessels have evolved to complement the sea conditions and fishing methods unique to each particular region. Like fishing gear, boats have passed the test of time. Nevertheless, traditional craft are not without their problems. They often have a very limited range of operation and are not able to go beyond heavily fished nearshore areas. Many will sink if swamped, providing no reserve of safety. Customary building materials are often unavailable. Deforestation in many coastal areas has created a scarcity of quality wood for dugout canoes and larger craft.

Traditional boats can be improved, often without radically altering the basic design; a respect for tradition will increase their acceptance. New vessels should have improved fishing capabilities. Increased seaworthiness and better fuel performance would permit fishing further offshore for previously unexploited species. Working and storage space could be increased, creating better working conditions and facilitating an increased catch. In areas without harbors, beachable craft are a priority. Improved designs should also help ensure the safety of the crew by including a second means of propulsion and sufficient buoyancy so that the vessel remains afloat when flooded.

Cost effectiveness is a fundamental requirement. The value of the daily catch must exceed the operational costs and help amortize the construction costs within a reasonable time. In essence, the boat should require low investment, use minimum fuel, catch as much fish as possible, and have a long service life.

This chapter covers some design considerations, examines some new boat construction methods and materials, and describes a few propulsion techniques.

DESIGN

A fishing boat may be described as a floating platform used to transport the crew, gear, and cargo to and from the fishing grounds and to support the crew and equipment during the fishing operation.

Some of the major factors that affect the design of this platform include:

- Available funds
- Available materials
- Skills for building and maintenance
- Size limitations dictated by water depth or requirement for beaching
- Distance to fishing grounds
- Fuel costs
- Type and quantity of gear used
- Vessel speed requirements
- Number of crew, standard of accommodation, cooking facilities
- Methods of bait and catch preservation
- Safety features.

Usually when a decision is made to introduce new equipment to an existing fishery, the purpose is to fish for a new species or to fish in a new area. New boats, new gear, or both may be needed. In some fisheries, it may be necessary to introduce a few larger vessels. Unless a cooperative system already exists, serious problems of equity can arise when a small group gains significant advantage in productivity through access to new large vessels. The introduction of small, high-speed outboard-motor-powered boats has also brought its share of problems. When the costs of fuel, motor repair, and replacement reach a significant percentage of the fisherman's income, the attractiveness of speed diminishes (figure 1.1).

Figure 1.1
For some fishermen, the costs for fuel and engine repair can approach the value of the catch. (D. Suman)

Small craft design should be based on the traditions of a given region. Vessel sizes and designs that have evolved in an area are usually well adapted to the local fishing gear and methods, the range of operations, construction materials, the winds, and local sea conditions. A radical departure from the traditional hull design may not gain local acceptance.

Rafts are keelless vessels that are common in many areas of Asia. They may be constructed of bamboo, logs, or plastic cylinders, lashed or fastened together. These vessels are beach-landing craft, well suited for heavy surf conditions that would exclude many other boat types.

The *kattumaran* of South India is a wooden log raft that ranges from 3 to 9 m long. Each log is individually shaped with a definite fore and aft curvature. Longer logs are placed inboard and shorter ones outboard, and all are lashed together. Planking is then nailed over the logs to provide a smooth working surface.

Single-hulled vessels are most commonly used in small-scale fisheries. Designs with a high length to beam width ratio and a low displacement* to length ratio have less resistance per unit of displacement than do fat, heavy hull forms. Therefore, narrowing the beam, lightening the draft,** and decreasing the displacement-length ratio will result in less fuel consumption at a given speed.

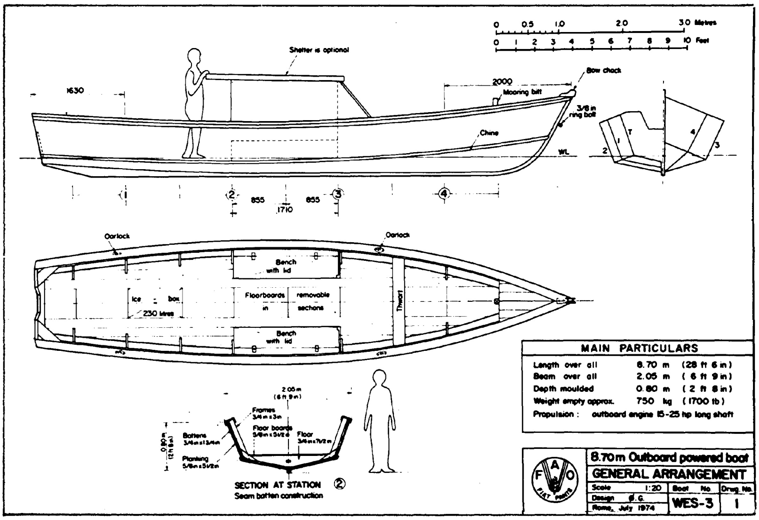


Figure 1.2
This FAO-developed 8.7-m boat was specifically designed for village fishery use.

A number of FAO-designed hulls based on these principles have been adopted in the South Pacific. The FAO 8.7-m boat (figure 1.2) has been designed as an easily propelled, narrow beam, light displacement craft suitable for village fishery operations. An outboard-powered model of this craft has been built in Western Samoa for US$1,250. With a crew of 4 and a 200-kg catch, the vessel can achieve a speed of 10 knots with a 20-hp outboard motor.

Multihulled vessels, such as catamarans and trimarans, have traditionally been used as fishing boats in the Pacific Islands. They show promise as fishing boats in other areas, especially where fishermen use one or two outriggers and are accustomed to the idea of multihulls.

* Displacement: the weight or volume of water displaced by a boat.
** Draft: the depth of water that a boat displaces.

Figure 1.3
The Sandskipper 24 catamaran has been successfully introduced in Sri Lanka. Weighing only a ton, it can carry up to 3 tons of fish and gear. (E. W. H. Gifford)

Multihulled boats have a number of positive features for small-scale fisheries. Their hulls have low displacement to length ratios and high length to beam ratios (long and narrow) and therefore offer minimum resistance and are easily propelled. Moreover, the stability of multihulls makes them ideal candidates for sail power. Small catamarans are lightweight and can be beached and carried with relative ease.

Several development projects are attempting to introduce small fishing catamarans and trimarans into areas that traditionally have used monohulls. A number of catamarans have been introduced into the tropics by Gifford and Partners of Southampton, England. One of them, the Sandskipper 24 (figure 1.3), is gaining acceptance in Sri Lanka as a beachable fishing vessel. It has a lateen sail and a diesel engine as propulsion options. This vessel design has proved very satisfactory for gill netting. It can carry a ton of gear and up to 2 tons of catch in good weather.

CONSTRUCTION

Traditional dugout canoes and bamboo rafts are common throughout the Third World (figure 1.4). The construction materials are usually inexpensive and available locally. However, both materials severely limit the hull shape and are relatively short-lived. Wooden logs are heavy and can result in high fuel consumption. While bamboo has the advantage of being lightweight, it is not especially durable.

Wood and bamboo will remain important boatbuilding materials in coastal fishing villages where they are readily available. Where there is a scarcity of good wood, there may be no alternative to adopting new materials. Newer materials and methods can offer many advantages that compensate for their increased cost. The choice of material will depend upon a number of factors including cost, availability, longevity, ease of repair, strength, and resistance to corrosion and rot.

Wood Construction

Timber

Planked hulls have been constructed for hundreds of years throughout the world, and in many areas they are still very popular and highly regarded. Nevertheless, their importance is clearly diminishing as new construction materials are accepted (figure 1.5).

Several variations of planking are commonly used. In carvel planking, the outside planking is laid edge to edge, giving the hull a smooth surface. If the planks are very narrow (2.5-4 cm wide) and wedged together with the edges fastened, the method is called strip planking. Marine glue or caulking is used to keep the seams watertight.

In clinker planking, each plank overlaps the upper edge of the plank below and is attached to it by nails driven from the outside. This variation is strong and flexible and is ideal for such small craft as dinghies.

Wood can be a very satisfactory boatbuilding material: it has good resistance to chafe, gives thermal and acoustic insulation, and allows great variation in hull shape. If good timber is available locally and is economical, it is a logical choice. However, in many tropical coastal regions, suitable boatbuilding timber is scarce and expensive. Another disadvantage is the high degree of skill required to build a wooden boat. With only hand tools, construction can be very time-consuming. The hulls produced are of medium weight and, as they become increasingly waterlogged

Figure 1.4
Cuba tribesmen in Panama still have the logs and skills for shaping dugout canoes. (D. Suman)

with age, consume large amounts of fuel. Many woods are also subject to rot and attack from marine borers.

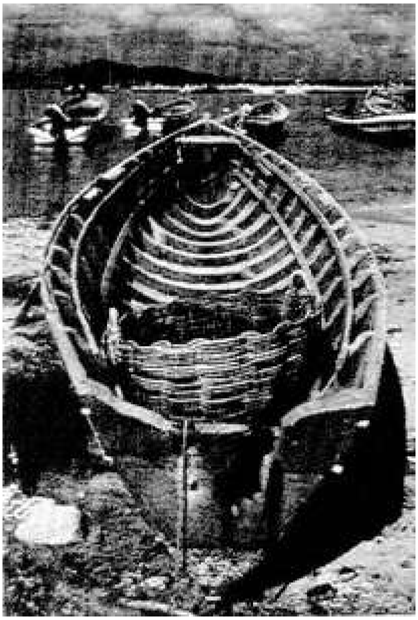


Figure 1.5
In Martinique, a traditional planked hull wooden boat rests on the beach; several fiberglass reinforced plastic boats float just off shore. (D. Suman)

In Tahiti, V-bottom *bonitiers* are built of imported redwood planking with local timber used for the frames. Hot dipped, galvanized carvel nails are used for the fastenings. These boats are reported to last well, in spite of being stressed when they are run at high speeds.

Plywood

Plywood is a sandwich of wood veneers and filler material held together by adhesives. There are many grades of plywood, but generally, marine plywood made with a waterproof adhesive is required for boatbuilding. Lower grade plywoods can sometimes be upgraded for marine use if they are coated with a polyester resin.

Plywood is very adaptable to small boatbuilding operations.

It is light, can be cut to any shape, and is easily bent. Since sections are cut from large plywood sheets, there are fewer seams than in planked boats. Plywood construction involves building a framework for the hull from planks and then attaching sections of marine plywood to this frame. The plywood hull is held together by nails; marine glue is used to seal the seams.

Plywood boatbuilding can be quick, inexpensive, and easy. As long as the surface, and especially the edges, of the plywood are treated with epoxy resin or another sealer, the boat will have a long life. However, the use of plywood does restrict the hull to hard chine shapes, such as flat or V-bottomed boats. Moreover, its resistance to chafe is not high.

There are many successful examples of plywood boats built and used throughout the world.

Some 250 plywood versions of the Alia, an 8.5-m fishing catamaran, were built in Western Samoa in the 1970s and have survived almost a decade without hull rot or delamination. These *vessels* have an emergency sail but rely on outboard motors as their principal method of propulsion. Fishermen generally employ these catamarans for trolling and handlining. In Fiji, more than 130 V-bottom fishing boats (8.6 m) have been constructed of plywood. They are equipped with inboard diesel motors and are also used primarily for handlining and trolling.

A plywood single outrigger canoe was designed by FAO in 1985 specifically for the waters of Papua New Guinea (figure 1.6). This 7-m canoe is sail-assisted and is designed to use an 8-hp outboard motor. The outrigger is filled with foam and helps support the weight of two or three persons in the canoe. In sea trims it was shown that this new vessel equipped with an 8-hp outboard engine was faster than a traditional dugout, powered with a 25-hp engine, and could travel about twice as far on the same amount of fuel. Similar plywood outrigger canoes (proas) have proved their worthiness throughout the South Pacific where they can replace canoes made from timber.

Plywood skiffs have wide acceptance throughout the world as inexpensive, rugged work boats. In southern New England (United States), plywood skiffs are extremely common and are used for lobstering, trawling, and gill netting. With good waterproof adhesives, these skiffs can have a 15-year service life.

Marine plywood is also used in the stitch-and-glue technique (figure 1.7). Precut sections of plywood are wired together with galvanized wire; the seams are then sealed with epoxy resin. The final connection is made by bonding the epoxy resin glue with glass fiber. Once the resin has set, the wires can be cut and a finish applied. The product can be a strong, light boat with a life expectancy at least as good as traditional timber vessels.

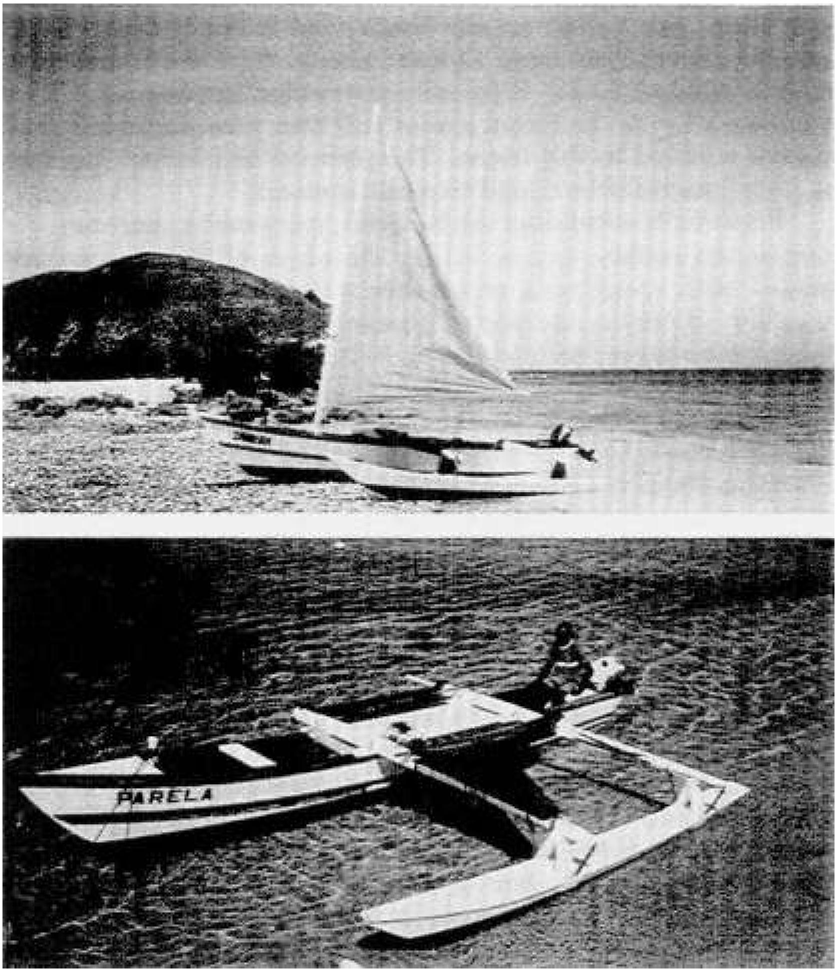


Figure 1.6
In Papua New Guinea, plywood outrigger fishing boats have been introduced to replace dugout canoes. The new vessels travel faster with an 8-hp engine than do the traditional canoes with a 25-hp engine. (Designer: O. Gulbrandsen; photo: D. Cook)

Boat construction by this technique is easy and fast. Precut sections of marine plywood may be assembled in a village workshop without sophisticated equipment. Skilled carpenters are not required, but it may be necessary to import the epoxy resin and glass fiber.

This boatbuilding technique has been introduced at the Muttom Cooperative Boatyard in Tamil Nadu, southern India, in cooperation with the Intermediate Technology Industrial Services of England. A number of different designs have been constructed to satisfy coastal conditions, crowded beaches, and the need for more space to carry nets.

Another new boat design constructed by stitch-and-glue methods is the ply vallam (figure 1.8). Traditional vallams are dugouts made from large mango trees. Having narrow hulls with limited stability, they are almost impossible to sail windward except in very light winds. Ply vallams are wider at the gunwale than traditional boats and have increased stability. This permits the fishermen to sail in any direction with increased safety, thus boosting their fishing potential. Cheaper than the traditional craft, it has been well accepted by fishermen. The ply vallam is now in service at Quilon, Kerala State, South India.

Double-hulled boats have been constructed by stitch-and-glue methods. They can be landed on the beach and offer stability and a large platform for fishing. One small version, the 4.8-m Sandskipper, was also introduced into South India (figure 1.9). It can carry half a ton of gill net and an additional ton of catch.

A plywood houri has also been designed as a replacement for the dugouts and planked houris of the Indian Ocean (figure 1.10). Built from only 4 sheets of plywood, it can be rowed, paddled, or powered with a 4-hp motor.

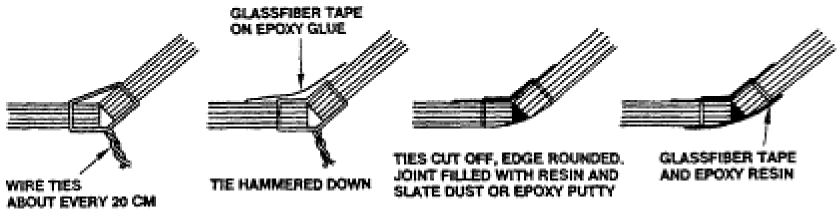


Figure 1.7
The stitch-and-glue construction method involves wiring plywood sheets together, sealing the joint with epoxy resin, and finishing the seal with fiberglass tape and additional resin.

Figure 1.8
In India, traditional vallams are dugout canoes made from large trees. Plywood vallams (left) have been made as substitutes using the stitch-and-glue method. (C. Palmer)

Cold-Molding

The boat-construction technique known as cold-molding uses veneers or thin plywood strips to build up a laminated hull. The veneers are applied in diagonally opposed layers. The thickness of the veneers varies in proportion to the hull size, but typically they are from about 2 mm to about 10 mm thick. These thin boards can be produced by a plywood mill or with a band saw or circular saw.

One cold-molding method involves fabricating a mold that provides surfaces on which the planking is stapled. The veneers must be carved to a shape that will fit with their neighbors. The first layer of veneer is stapled longitudinally to the frame (figure 1.11). Epoxy adhesive or another gap-filling glue is applied to this first layer, and a second layer of veneer is stapled diagonally over the wet, uncured glue (figure 1.12). A third layer of veneer may be placed diagonally to the second.

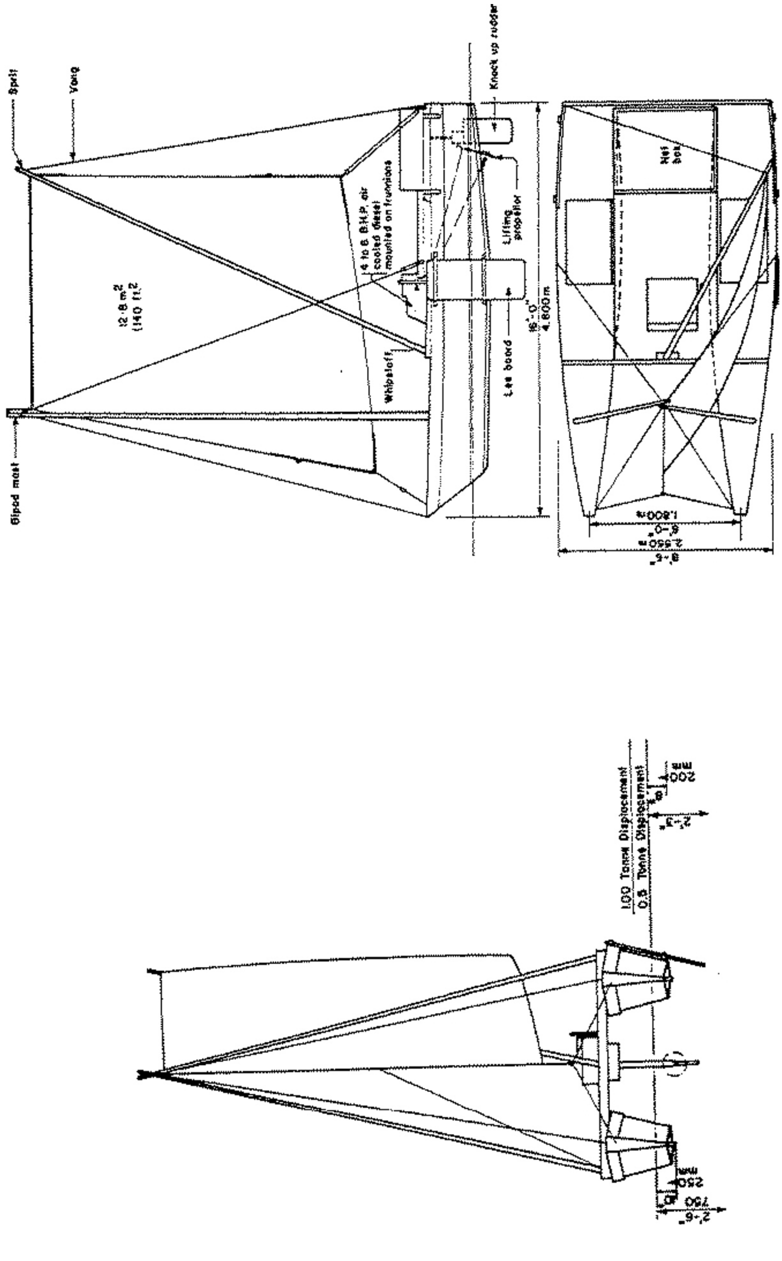


Figure 1.9
Double-hulled boats have also been constructed by the stitch-and-glue method. This 4.8-m boat has been introduced in South India. (E. W. H. Gifford)

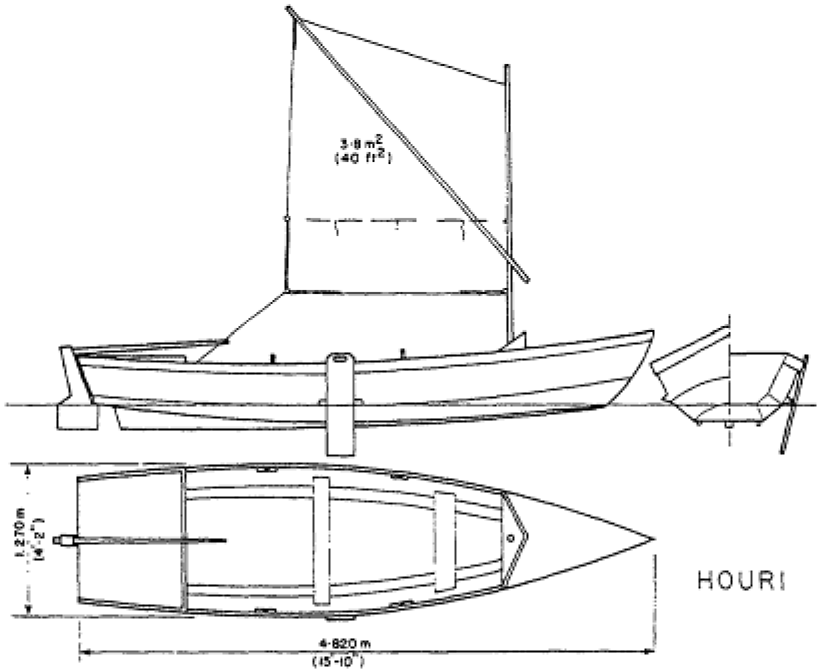


Figure 1.10
A plywood houri has been designed as a replacement for the planked houris of the Indian Ocean. It is intended to be built using only four sheets of plywood. (E. W. H. Gifford)

After lamination has been completed, the frame can be removed (figure 1.13) and the staples clipped. The gunwale and keel are then attached. If necessary, a fiberglass-epoxy resin coating can be applied inside and outside the hull (figure 1.14). A water-repellent preservative or paint will protect the wood satisfactorily.

The cold-molding technique creates a very light and strong hull, resulting in low fuel consumption. These relatively thin hulls are not highly resistant to puncture but this can be improved by increasing the fiberglass-resin layer. Although in most areas it is probably easier to obtain veneers than good timber, the adhesives may have to be imported.

"Constant Camber" is an improvement on this lamination technique. It requires a reusable mold shaped like a curved trellis (figure 1.15). The hull geometry is such that the veneers can be precut and can be easily mass produced. Each veneer strip does not have to be hand carved to fit perfectly with neighboring pieces.

Another great advantage is that one mold can produce various hull sizes and types.

The mold is best suited to hull forms that have a relatively constant amount of curvature throughout, such as the long narrow hulls of multihulled vessels. However, wide-body hulls can also be produced, and craft as long as 19 m have been fabricated.

Using the Constant Camber process, the veneers are bent diagonally across the mold and stapled, as in cold-molding. Additional layers are held by epoxy resin and can be applied immediately. No screws or nails are required in the process. The staples can be left in and later cut and sanded down.

Alternatively, a process called vacuum bagging can be used to eliminate the need for staples. The defects in the wood are filled with glue and even imperfect wood can be substantially strengthened. The reusable equipment for vacuum bagging costs about $500.

The resulting veneer-epoxy composite is stronger than the original wood itself. The hulls are strong, light, waterproof, and rot-resistant, and have a predicted life of 20 years.

Figure 1.11
The first step in producing a boat by cold-molding is to staple thin strips of wood to a reusable wooden mold. (Agro-Forest Products Intermediate Technology Associates—AFPITA)

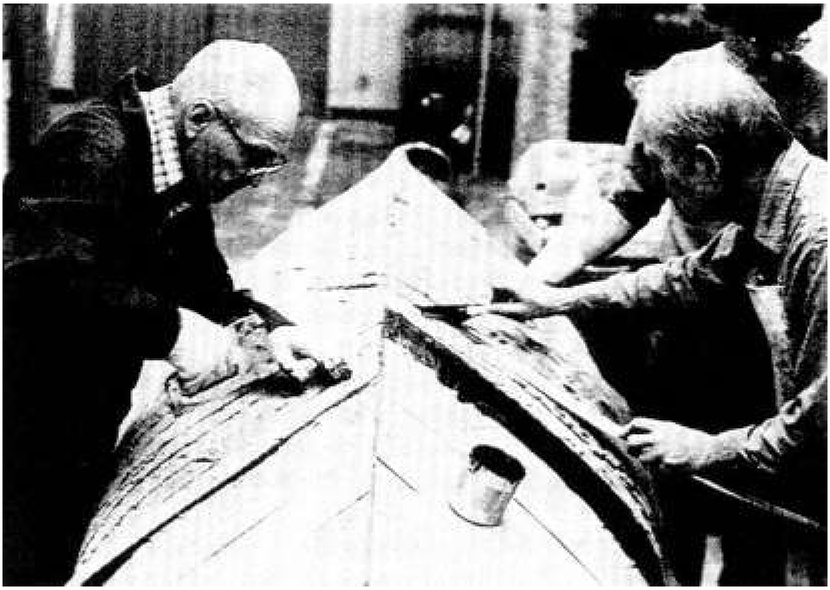


Figure 1.12
A gap-filling glue is then applied to this first layer and a second layer of wood strips applied diagonally over the wet glue. More glue and a third layer of strips can then be added. (AFPITA)

A 35-foot panel can be laminated by several people in a matter of hours. Two half-hull panels are then sewn or glued together to form the hull (figure 1.16). Plywood or veneers of fast-growing woods could be obtained locally in many Third World villages and the molding technique learned by village craftsmen. Liabilities are the lack of expertise in using this relatively sophisticated method.

The Constant Camber technique has been used to construct a fleet of 100 paddle-powered catamarans used by Burundi fishermen on Lake Tanganyika. These boats are especially energy efficient because they are easily paddled. A local wood was used for the veneers, but most of the equipment and adhesives as well as the expertise had to be imported.

In Tuvalu in the South Pacific, several Constant Camber catamarans transport people and cargo around the atoll lagoons (figure 1.17). These boats were originally financed by the Save-the-Children Federation but are now self-supporting. Over 100 smaller wood-epoxy boats have recently been constructed there.

Figure 1.13
After lamination is complete, the frame can Be removed from the mold and the Boat finished. (AFPITA)

Figure 1.14
An additional resin coating can be applied to the boat to ensure a uniform protective surface. (AFPITA)

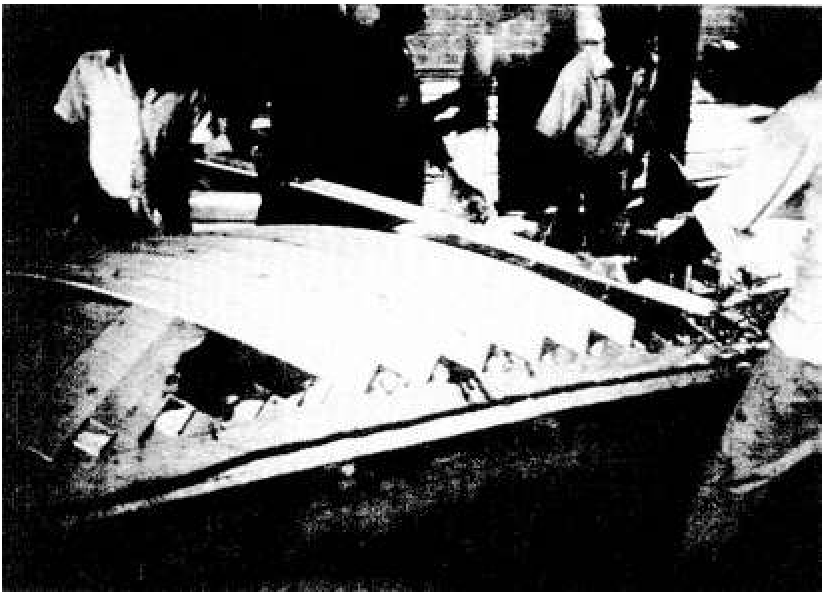


Figure 1.15
The Constant Camber technique uses a specially designed hull mold that permits all the wooden strips to have the same shape. (J. Brown)

Non-Wood Construction

Ferrocement

Ferrocement is the term used to describe a steel-and-mortar composite material (figure 1.18). It differs from conventional reinforced concrete in that its reinforcement consists of closely spaced, multiple layers of steel mesh completely impregnated with cement mortar. Ferrocement can be formed into sections of less than an inch thick. Ferrocement reinforcing can be assembled over a light framework into the final desired shape and mortared directly in place.

Ferrocement Boats are usually constructed close to the water's edge because of their weight. The Building site should be chosen · with the size of the craft, its draft, and its launching in mind.

There are five fundamental steps in ferrocement boat construction:

(1) The shape is outlined by a framing system.

(2) Layers of wire mesh and reinforcing rod are laid over the framing system and tightly bound together.
(3) The mortar is plastered into the layers of mesh and rod.
(4) The structure is kept damp during the cure.
(5) The framing system is removed (unless it has been designed to remain as part of the internal support).

There are several ways to form the shape of the boat. A rough wooden boat can be constructed as a matrix or an existing, perhaps derelict, boat can be used. Pipes or steel rods may be used to frame the shape of the hull. In the construction of Chinese sampans, a series of welded steel frames and precast ferrocement bulkheads are erected. Layers of wire mesh are then attached to this framework and mortar applied. The steel frames and ferrocement bulkheads are left in place as part of the boat structure.

Using these and similar techniques, ferrocement boats from 8 to 20 m long have been constructed. Above and below this size range there has not been enough experience to recommend this type of construction. Ferrocement hulls less than about 8 m are usually heavier than comparably sized hulls in wood, steel,

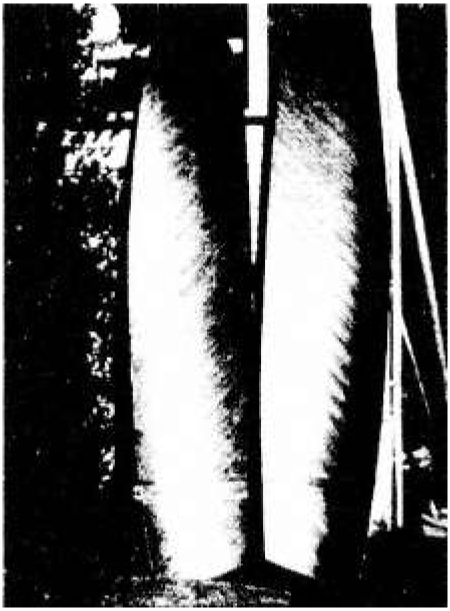


Figure 1.16
Larger boats can be built using the Constant Camber method by producing half-hull panels and joining these. (J. Brown)

or fiberglass. This characteristic also prohibits ferrocement use in multihulled vessels.

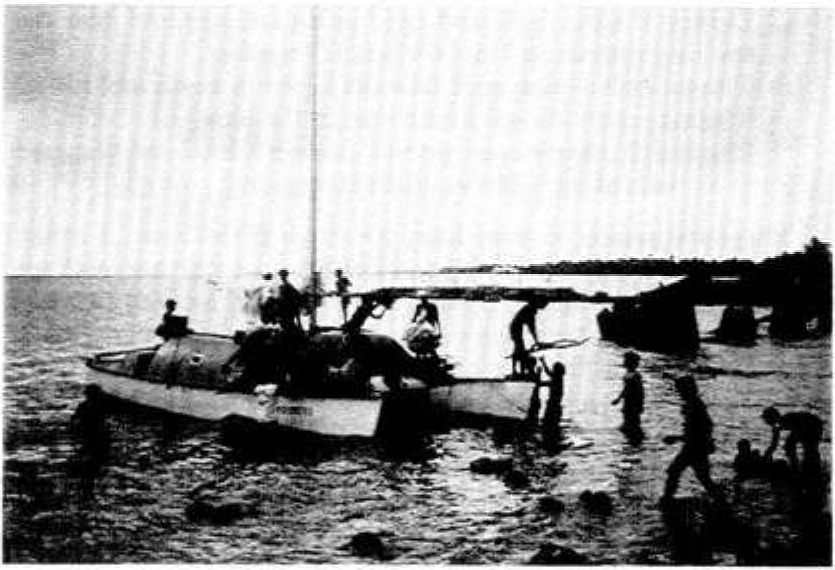


Figure 1.17
In Tuvalu interisland transport of people and cargo is provided by catamarans built using the Constant Camber method. (J. Brown)

Problems with chafing, penetration by sharp objects, and saltwater corrosion of the steel mesh have also been reported. Perhaps the most positive aspect of ferrocement as a construction material is the very low cost of materials. A high percentage of materials can usually be obtained locally. Construction is straightforward and rapid.

Any desired hull shape can be produced in ferrocement. Because the hull is homogenous, there are no seams to leak. Damage from impact simply requires chipping away the broken concrete, reshaping the mesh support, and applying new cement. The repair process is easier and cheaper than repairs for many other materials.

Ferrocement boats have been constructed and operate in Southeast Asia, South Asia, the South Pacific, and Africa. Many of these boats have been pilot projects, but in some cases, ferrocement has become a leading boatbuilding material.

In 1969, Cuba began construction of its first ferrocement model. During the subsequent 15 years, ferrocement has become the favorite construction material for Cuban boats. Cuban shipyards and the Center for Naval Projects and Technology (CEPRONA) have designed and produced more than 1,000 ferrocement vessels—from shrimp boats to large longline fishing boats.

The People's Republic of China has also opted for ferrocement sampans for use on inland waterways. Thousands are now in use on China's Grand Canal.

Plastic Tubes

Rafts in Taiwan have been traditionally made of bamboo; although very strong and light, this wood is also short lived. The bamboo is being replaced by sealed plastic (PVC) tubes that are 15 cm in diameter. Plastic tubing is durable and inexpensive, resistant to marine borers and rot, and does not react with salt water or become waterlogged. Nevertheless, the vessel design is very restricted.

Figure 1.18
Ferrocement boats can be produced in most countries with locally available materials. (N. Vietmeyer)

From 6 to 20 4-m-long pieces of plastic tubing are fastened together to construct the raft. The first meter of tubing at the bow is curved upward at 45° to minimize resistance to the water (figure 1.19).

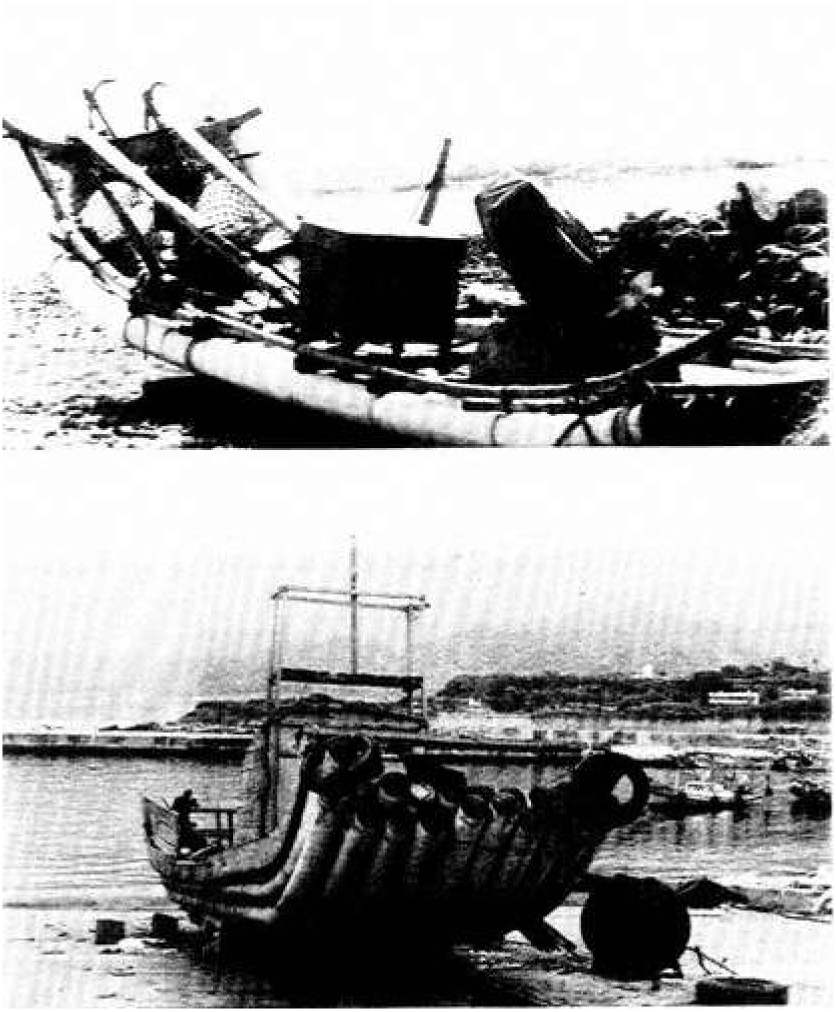


Figure 1.19
In Taiwan, plastic tubes are used in single layers to make small rafts or in double layers to produce larger rafts. (T. J. Lee)

The one-layer type of plastic raft is used in coastal fry collection or in set net operation; the two-layer type is used in drift net or long net fisheries. Inboard diesel motors are generally used to propel the plastic rafts. Sail power seems to have fallen into disuse with this vessel.

Fiberglass-Reinforced Plastic

Fiberglass-reinforced plastic (FRP) has gained increasing acceptability as a structural material for boats since the 1950s. This material was first used for pleasure craft and is now increasingly used to construct fishing boats in the Third World.

FRP is a composite material made of fiberglass and a polyester resin. The fiberglass provides the material's strength, and the resin, which is absorbed by the fiberglass, allows the material to be easily shaped.

After a prototype has been chosen, a female mold is manufactured. A polyester resin gel coat is sprayed onto the mold's surface, and then fiberglass and more resin are used to laminate the hull. After transom and keel reinforcements have been installed, the hull is removed from the mold.

FRP is an outstanding construction material for boats. Virtually any complex hull shape can be created. Because of the one-piece hull structure, leakage is practically impossible. The material is highly resistant to scratching and does not rot, rust, or corrode. Thus, less maintenance time is required, and durability is good. FRP shells have a much higher strength-to-weight ratio than similar wooden shells and are also lighter. The actual boat construction does not require high skills or special tools.

The major disadvantage of FRP is the cost of materials. Fiberglass and polyester resin often must be imported at high cost. The development of the female mold required for production is an additional expense. Repair of the hull in remote areas may also be a problem.

The resin presents some difficulties for the tropics because it must be stored in an air-conditioned room and replenished every 6 months. The fibers and resin also can be hazardous to the health of the workers.

Well-conceived and financed FRP fishing boats can be successfully introduced in the Third World if they are economically feasible. The modernization of the traditional canoe fleet has been a priority in Senegal. A prototype diesel-powered beachable fishing boat constructed of FRP was developed by Yamaha especially for the situation there. The Loa 12.8-m canoe (figure 1.20) has the same length-to-breadth ratio as the traditional wooden canoe but offers an innovation in the hull. The bow is shaped like a ram's horn to facilitate beach landing and hauling of the canoe. The sea trials of this vessel have been satisfactory.

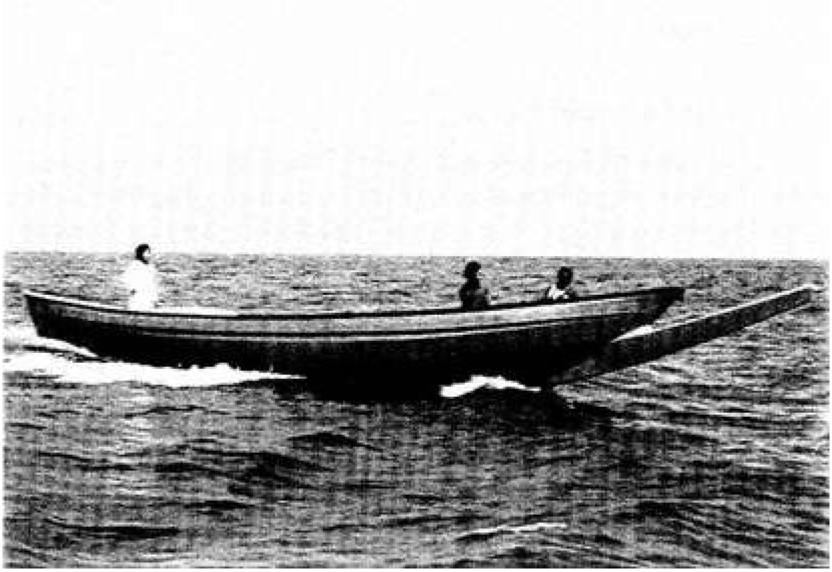


Figure 1.20
FRP boats have been successfully introduced in Senegal. This boat has largely replaced traditional fishing canoes. (T. Fukamachi/Yamaha)

A smaller model, the Loa 9.2 m (figure 1.21), was introduced to the Comoro Islands and the Malagasy Republic in 1983. This sail-assisted, diesel-powered canoe is meant to be a replacement for the traditional double outriggers (pirogues). The Loa 9.2 m has a double outrigger that adds stability and transfers a characteristic of the traditional canoe that is familiar to fishermen. The outrigger floats are made of FRP and the beams of aluminum pipes. It is not clear yet whether this new FRP model yields improved profits, but its sea trials are very satisfactory.

A similar sort of boat evolution has occurred in Sri Lanka through FAO's Bay of Bengal Program. The traditional oru is a Pacific proa-type vessel with a single outrigger. Built of jak timber, it is seen in sizes from 15 to 40 feet. Because of the shortage of large jak timber, the FAG program designed an FRP oru that involves a modification of the hull but retains the traditional rudders and rigging.

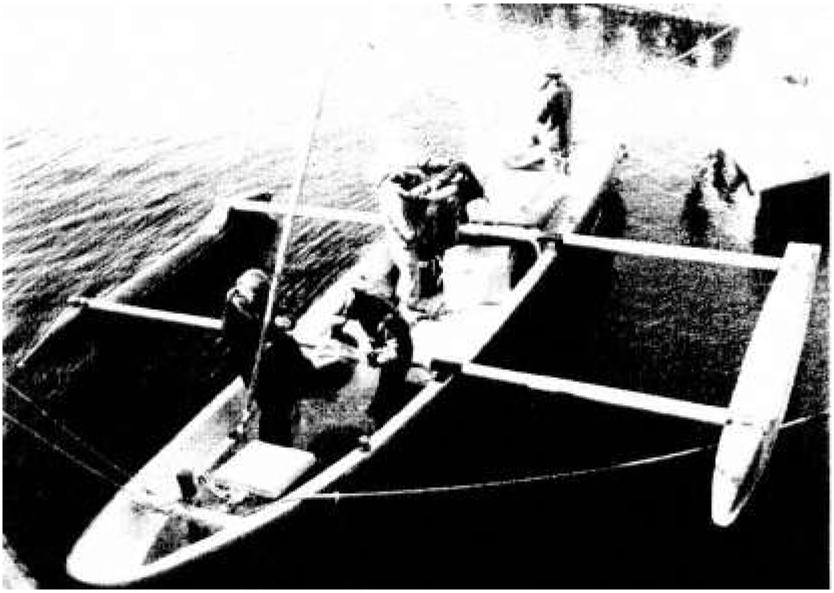


Figure 1.21
In the Comoro Islands, this sail-assisted diesel powered canoe is designed to replace the traditional double outrigger pirogues. (T. Fukamachi/Yamaha)

In some locations, such as the eastern Caribbean, FRP is also used to sheath traditional wooden vessels to extend their lifetime. The Bay of Bengal Program has proposed to protect the logs of South India's traditional *kattumaran* with FRP sheathing.

C-Flex

C-Flex is a fiberglass planking that can be used to build boats without the standard mold required for fiberglass-reinforced plastic boat construction.

C-Flex is composed of parallel rods of fiberglass and reinforced polyester resin alternating with bundles of continuous fiberglass rovings. This structure is held together by two layers of lightweight, openweave fiberglass cloth. Each plank is 112 cm wide.

The planks are laid over plywood frames, tacked in place, and covered with resin. Fiberglass mats are then applied at right angles to the C-Flex. Sanding and a final finishing complete the process.

C-Flex offers all the advantages of FRP as a construction material, except that the strength-to-weight ratio may not be quite as high. No mold is required, which greatly lowers costs and permits decentralized village construction. An additional advantage is that few tools and equipment are required.

Even though the absence of a mold cuts costs, the C-Flex must be purchased through a company in New Orleans (United States). In many locations, the fiberglass and laminating resin would have to be imported, resulting in a costly product.

The International Center for Living Marine Aquatic Resources Management (ICLARM) in the Philippines designed and constructed an experimental small fishing boat using C-Flex. The hull is 6 m long, has a shallow draft, and is beachable. Propelled by an inboard engine, the craft also has a sail-assist option. ICLARM suggests that the fiberglass material accounts for about two-thirds of the cost of supplies.

Aluminum

Construction of small aluminum vessels involves standard metal-working techniques. Aluminum plates are cut and bent to fit the frame of the hull. Welding and riveting are then used to seal the seams and fasten the plates.

Aluminum alloys are excellent materials for small vessels. They can be shaped to almost any hull form and produce a greater variety of shapes than glued wood can. Aluminum is also light, which is another advantage, because it reduces the displacement and results in low fuel consumption. In addition, aluminum shows a high resistance to chafe, has an excellent strength-to-weight ratio, and holds up well under bending stress.

Aluminum oxide forms in a thin coating on the alloy and provides protection against corrosion. Thus, boats constructed of this material can have great longevity.

The disadvantages of aluminum are significant. The cost of aluminum alloys suitable for boatbuilding is very high, and the alloys may be difficult to purchase in small quantities. Although dents may be easily hammered out, punctures may require welding equipment, which is not likely to be available in coastal fishing villages. Moreover, aluminum is far more difficult to weld than steel and requires the high temperatures of arc-welding.

TABLE 1.1 Boatbuilding Materials Comparison: Construction

Construction Material	Cost	Availability of Materials	Skill Level	Time to Build	Hull Shape
Logs	1	1	1	2-4	3-5
Bamboo	1	1	1	1	5
Wood planking	2-3	1-5	5	5	1
Strip planking	2	2-5	3	2-3	1
Plywood sheet	2-3	3-5	2-3	2-3	3
Stitch and glue	3-4	3-5	2	2	2
Cold molded	3-4	3	2	2	1
Constant Camber	3-4	3-5	2-3	2-3	3
Fiberglass laminate	3-5	1-5	2	1	1
FRP sandwich core	4-5	1-5	3	2-3	1
Composite laminate	5	1-5	3-5	3	1
C-Flex	3-5	2-5	2	2	1
Aluminum	4-5	1-3	2-4	2-3	2
Steel	I	1-3	2	2-3	2-3
Ferrocement	2	1-2	1-3	2-3	1

Scale:
Cost: 1 = lowest cost
Availability: 1 = readily available
Skill: 1 = lowest level of skill needed
Time: 1 = least time required
Hull: 1 = highest flexibility in design

More than 150 aluminum versions of the Alia were constructed in Western Samoa. They have good fuel economy and have proven generally satisfactory, although a few developed cracks.

The characteristics of various boatbuilding materials are summarized in tables 1.1 and 1.2. In table 1.1, materials are compared in terms of their use in construction including cost, availability, skill level needed, building time, and design flexibility. In table 1.2, these same materials are compared for their performance, including strength to weight, fuel consumption, chafe resistance, service life, and ease and cost of maintenance.

TABLE 1.2 Boatbuilding Materials Comparison: Performance

Construction Material	Strength-Weight Ratio	Hull Weight Fuel Consumption	Resistance to Chafe	Longevity	Maintenance
Logs	5	5	1	3	—
Bamboo	1	1	3	5	—
Wood planking	3	4	2	1-3	4
Strip planking	2	4	2	1-3	4
Plywood sheet	I	3	4	3	5
Stitch and glue	1-2	2	4	3	5
Cold molded	1-2	2	4	1-3	2-3
Constant Camber	I	2	4	1-3	3
Fiberglass laminate	2	3	2-3	1-2	1-2
FRP sandwich core	1-2	I	3-4	2-3	1-2
Composite laminate	1	1	1-3	1-3	1-2
C-Flex	2-4	3-4	2	1-2	1-2
Aluminum	1	1	1-3	1	1-2
Steel	3	4	1	1-3	2-4
Ferrocement	5	5	2-3	3	2

Scale:
Strength-Weight: 1 = high ratio
Hull weight and Fuel consumption: 1 = low weight and low fuel consumption
Chafe: 1 = highly resistant
Longevity: 1 = long life
Maintenance: 1 = low cost and less difficult to maintain

PROPULSION

New technologies in propulsion include alternative fuels, alternative engines, and unconventional wind-based methods. Alternative fuels include biomass-derived gasoline and diesel-fuel substitutes. Alternative engines include units powered by steam and producer gas. Unusual types of sails and wind-powered rotors complete this section.

Alternative Fuels

Both alcohol (ethanol) and vegetable oils have been examined as potential alternative fuels for small island communities. It was proposed, for example, that it would be possible to produce alcohol from cassava on one of the smaller islands in Fiji. Using a simple fermentation unit and distillation column, ethanol of 95 percent purity could be manufactured and used in modified outboard engines.*

Coconut oil and other vegetable oils have been examined for use in diesel engines. There have been three general approaches in the testing of vegetable oils as diesel substitutes. First, the oils can be used as 100 percent substitutes for diesel oil. In many short-term performance tests, vegetable oils have proved almost equal to diesel fuel. The use of pure vegetable oils in longer term endurance tests has rarely been satisfactory, however. Problems arise with coking and clogging of the injector ports and with fouling of the crankcase oil. Various blends of vegetable oils and diesel oil have also been tested. The use of 80:20 (or higher) blends of diesel oil to vegetable oil has generally proved satisfactory in both short-term and long-term tests. In the Philippines, however, when there was a national program to include 5 percent coconut oil in the diesel fuel, there were significant problems with clogging of fuel filters.

The most promising approach in the use of vegetable oils as diesel fuels involves their chemical transformation. Through the reaction of vegetable oil glycerides with alcohols (such as methanol or ethanol), the original high molecular weight glycerides are converted to methyl or ethyl esters, much closer in molecular size and shape to diesel oil. Performance tests with the esters derived from many vegetable oils have demonstrated good results in both short- and long-term testing.

Alternative Engines

Both steam- and producer-gas-powered engines have a special appeal for developing countries, that of fuel diversity. A wide variety of forest and agricultural products and wastes can be used as fuel in these systems. Using coconut-shell-derived charcoal as fuel, producer-gas-powered fishing boats have been tested in the Philippines.* The Intermediate Technology Development Group (ITDG) in London has begun development and testing of a small steam engine specifically for use in developing countries (figure 1.22).

Wind Power

Despite the presence of favorable winds in many areas, sailing as a means of propulsion for fishing craft in the developing world

* National Research Council. Alcohol Fuels: Options for Developing Countries. National Academy Press, Washington, D.C. 1983.
* National Research Council. Producer Gas: Another Fuel for Motor Transport. National Academy Press, Washington, D.C. 1983.

has declined in recent years. Wind patterns in the tropics are generally stable and predictable; large regions benefit from regular trade winds. In some areas, such as the northeast Indian Ocean, the China Sea, and Malaysia, fishermen continue to use their sailing skills. Large parts of Africa and Central and South America have not developed sail craft because they lack information, suitable materials, or incentive. Retrofitting sails to existing vessels can also be troublesome: hulls may not be suitably designed or sufficiently strong to accommodate masts or the strain imposed by sailing.

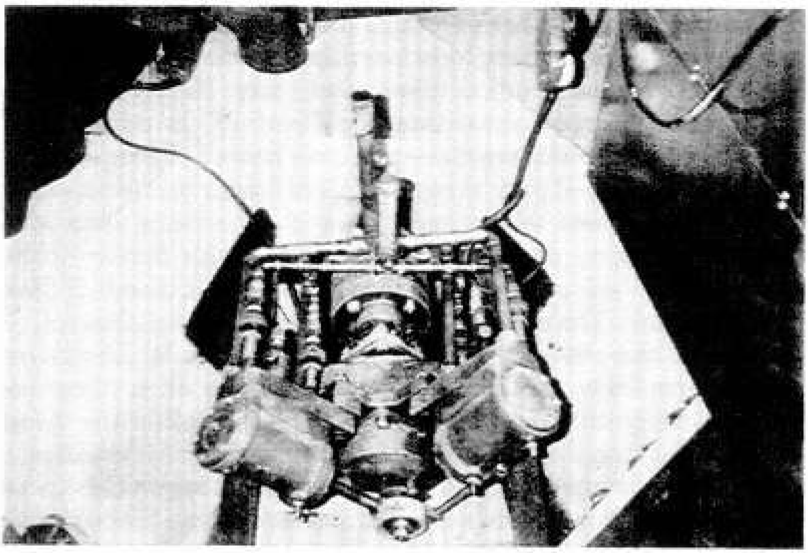
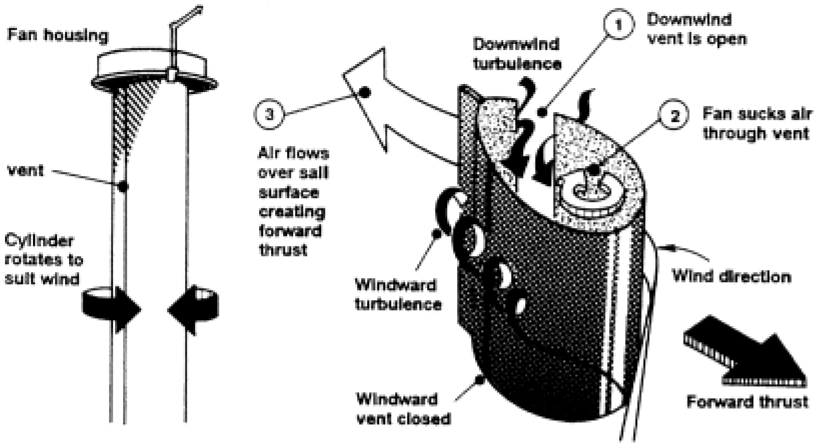


Figure 1.22
The Intermediate Technology Development Group has begun development of a small steam engine specifically designed to be used in fishing boats in developing countries. (D. Hislop/ITDG)

Natural or synthetic fabrics are most commonly used for sails. Dacron has proved to be one of the most durable and efficient materials for sails, but for most developing countries, local materials will be more practical and less expensive. Depending on wind strength and sail configuration, a sail area ranging between 1.9 and 6.5 m^2 (20-70 ft^2) is equivalent to 1.0 hp.

Exploratory research has also been done on hard sails, such as wingsails or airfoils. These can be up to twice as efficient as soft sails per unit area. The best wingsails can provide thrust up to 25-30 degrees from the wind direction. The Cousteau turbosail windship is shown in figure 1.23. This vessel also has diesel engines, which can be used when winds are light.



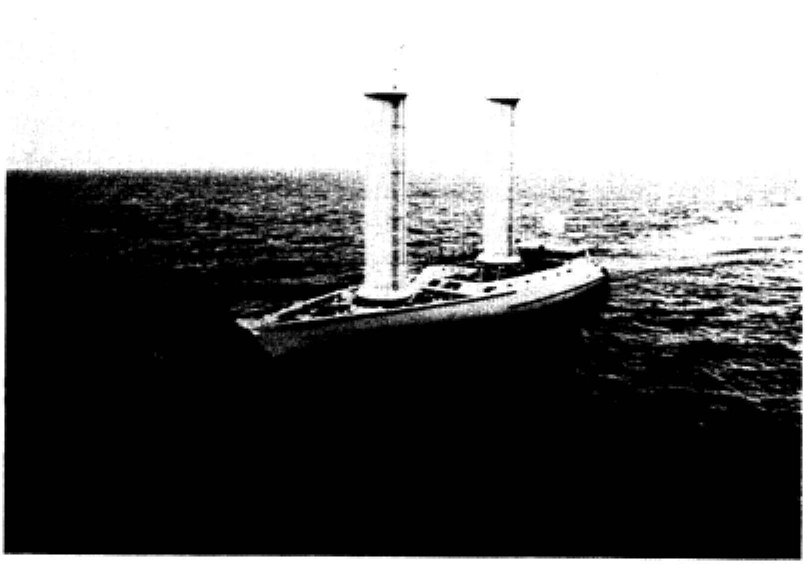


Figure 1.23
The 31-m Cousteau windship ALCYONE can be powered by its turbosails or its diesel engines or both. (Photo courtesy of the Cousteau Society, a member-supported environmental organization)

Human Power

Arm- and leg-powered devices including oars, paddles, and pedal-driven propellers have all been used for boat propulsion. A highly efficient racing shell requires about 230 watts (0.3 hp) effective power to attain a speed of 4 m per second (9 mph). Maximum instantaneous human output is about 1,500 watts (2.0 hp), but for a one-hour period, this decreases to about 500 watts (0.67 hp), and for 24 hours to about 370 watts (0.5 hp).

Since humans can probably produce more power by pedaling than any other endeavor, much could be done with pedal-powered propellers. Rowing is a relatively inefficient way to use human power for boat propulsion. Sculling, the use of a rear-mounted oar fixed on a fulcrum, is significantly more efficient.

LIMITATIONS

To gain ready acceptance of fishermen, changes or improvements in boat design and construction should not depart radically from traditional designs. This concern will be automatically satisfied if the local users play an important role in deciding the changes they would like to see in their boats. What works well in one area will not necessarily work well in another.

If new construction materials are used, they must be economical and, if possible, available locally. Local facilities must also exist for the repair and maintenance of the vessels.

Any new design must be appropriate for the fishing gear and methods that are locally used and, at the same time, must enhance the safety of the fishermen.

Before its introduction, a new vessel must first be carefully evaluated and modified as a prototype. Improvements should be recommended and adopted only when it can be clearly proved that they will give the fishermen greater net returns and be economically justifiable.

Improved vessel designs should not be encouraged in those coastal areas that are heavily overfished, unless the new craft can travel farther offshore and tap stocks that are unexploited at that time.

RESEARCH NEEDS

The design of small fishing boats deserves more attention.

Variations of traditional designs need to be tested to determine which give the best fuel and safety performances and are most appropriate for the accepted fishing methods. A series of small, highly efficient hull forms should be compared in single and multi-hull configurations. These results could suggest innovative vessels that might be easily accepted by local fishermen.

Materials' science has provided new materials that are excellent for boat construction. However, the cost of many of these materials is prohibitive to many fishermen. More emphasis should be given to lower cost, locally produced construction materials. Water-resistant glues manufactured from local materials (lignin, for example) would be an economic alternative to expensive imported epoxy or phenolic resins. Natural fibers might also serve as substitutes for fiberglass.

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2

Fishing Methods and Gear

Traditional fishing arts have been developed over the years to adapt to local conditions (such as the type of coast and nearshore area), the species of fish desired, and the size targeted. The most successful fishing methods of a given region are those that have stood the test of time.

This chapter will describe some of the traditional fishing methods used around the world and consider their advantages and disadvantages. Each method shows a continuum of development with evolution resulting from modernizing factors. Traditional fishing arts in various stages of modernization could be transferred and applied in new regions with the technical level appropriate for the local conditions. The adaptation of new technologies could help small-scale fisheries increase their catch. They could compete more effectively with industrial fisheries or exploit a previously unexploited resource. Energy-efficient technologies are recommended where possible.

The introduction of any new fishing technology always demands good national management and regulation. Vessels must also be matched with new methods or gear. As gear becomes more complex, it may require upgrading of vessels in size, power, and design. The site specificity of fishing arts should always be considered.

PASSIVE GEAR

Passive gear is stationary. It does not have to be dragged or towed to capture fish. Longlines, traps, weirs, and gill nets effectively fish by themselves. The catch is recovered by simply removing the gear from the water after a period of time.

Hooks and Lines

The simplest form of fishing requires only a line and a baited hook. The line is cast into the water where the fish supposedly are, the fish take the bait and are hauled in. Lines may be cast by ingenious methods. In Oceania, the line is wound around a stone and thrown from the shore into the water.

Hook and line fishing is inexpensive and easy. Almost any boat or shoreline can be used and the catch is live and of high quality. A wide variety of sizes and types of hooks and lures can be used, allowing very selective fishing. Tuna fishing with poles and lines continues to be widely practiced and productive.

In spite of these advantages, line fishing is labor intensive. A very limited number of fish can be captured per line and usually some type of bait is required.

Line-fishing methods can be made more efficient if multiple hooks on a line are used (figure 2.1). Often these are attached in pairs to form balanced lines. A single, branched rod, used in Lake Tanganyika fisheries, also allows one person to fish an increased number of lines and hooks. However, the number of lines that one person can hold is limited.

Set lines

The use of set lines can increase the number of lines deployed without requiring the constant presence of the fisherman. Such lines must be checked regularly because predators will devour any fish caught if the lines are not promptly recovered. Fishing rods can be set untended in shallow waters or on the beach. In the ocean, set lines may be suspended from the surface.

Longlines

Longlines are unwatched lines with multiple hooks. They can be used at the surface, suspended in the water column, or fixed on or near the bottom (figure 2.2). Japanese and Italian fishermen use sailing rafts to tow longlines away from their boats. Longlines may be set from the beach by means of sailing rafts or kites if winds are favorable. Surface longlines are used to capture tuna, shark, and billfish. Subsurface and bottom-set longlines are used to catch cod, grouper, snapper, drum, bream, halibut, haddock, hake, and flatfish.

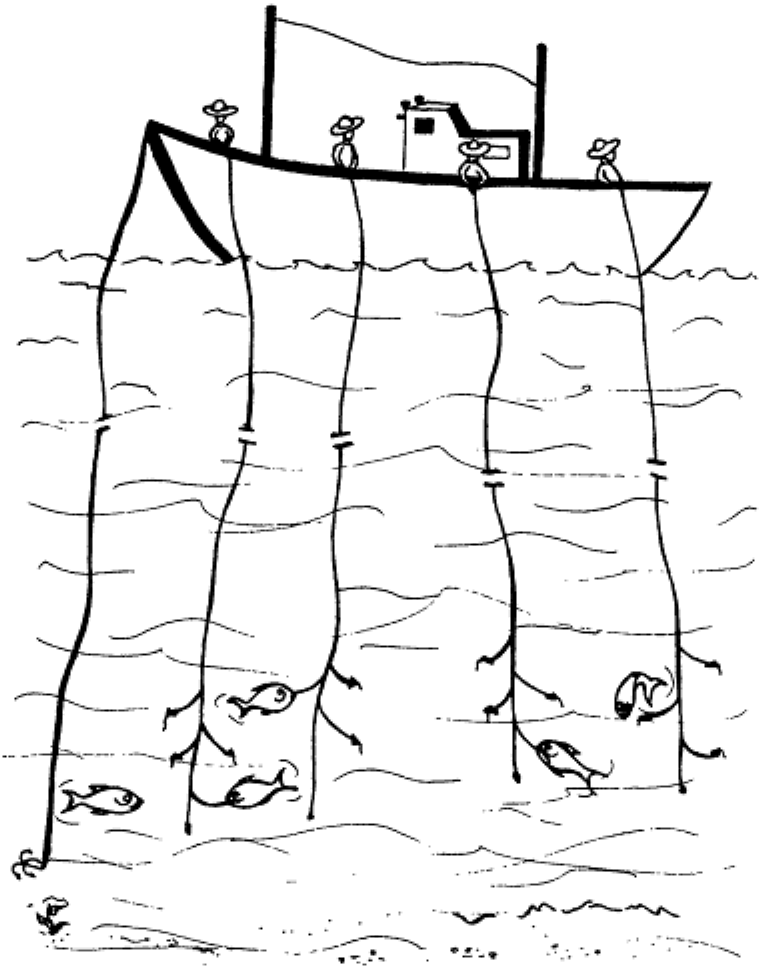

Figure 2.1
Multiple-baited hooks on a line can increase the catch.

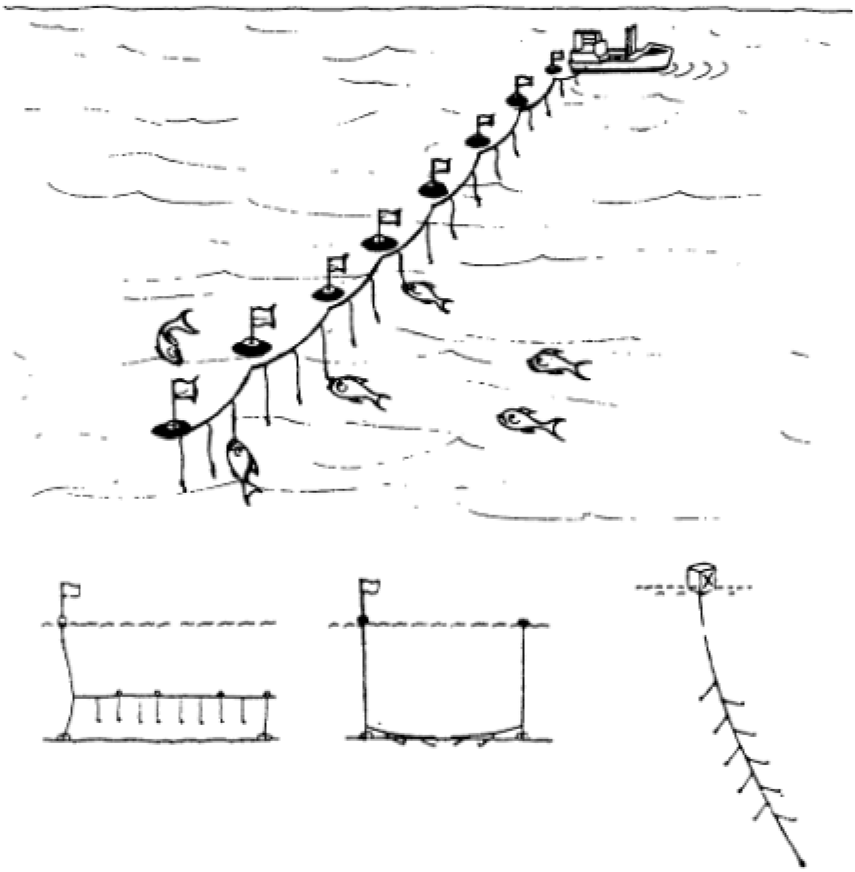

Figure 2.2
Longlines of Baited hooks can Be deployed at the surface, midwater, at the bottom, or vertically in the water column.

An alternative to bottom-set longlines is a vertical fish stick (figure 2.3). This device is hung from a surface float just off the bottom. It has rigid branches to allow multiple hooks without snagging. Fishermen can use local materials to fabricate this gear.

Hook-and-line fishing methods offer a number of advantages. They involve low capital and energy investments and labor-intensive operations. Species and size can be selected by the position of the hook in the water column, the hook size, and By the bait type

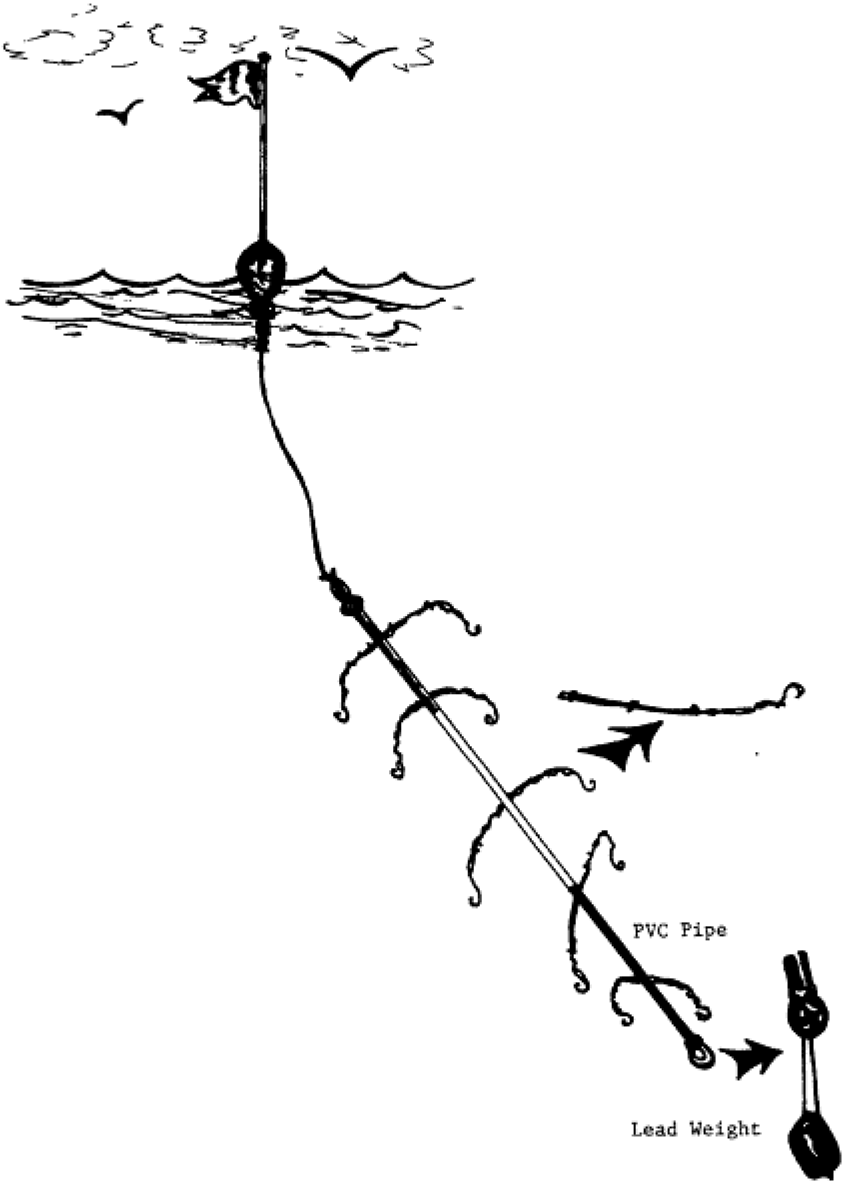

Figure 2.3
This 2.5-m rod has 5 rigid cross branches, each with 2 hooks. Adjacent cross branches are set at about 90° to each other for greater spacing between hooks. (Atlantic and Gulf Fishing Supply Corp.)

and size. Small-scale fisheries using only open boats can easily adopt hook-and-line methods.

At the same time, the hooks generally require bait (which may be expensive) and baiting is time consuming. It may be difficult to store longlines and their catch on a small vessel. Moreover, a high degree of skill is involved in deploying and retrieving longlines, unless expensive mechanized equipment is used.

Modernization in longline fisheries generally involves the mechanization of hauling. If available, hydraulic or electrical drives offer better control, lower maintenance, and variable power.

Simple mechanical hauling techniques can increase the range and depth of hand-line fishing. Manually operated reels can be constructed of local materials and used to reduce the effort needed to handle gear. A vehicle wheel (from a bicycle or automobile) can be fitted with a handle and mounted on the boat to create a simple roller, which facilitates handling lines or nets. A simple wooden hand hauler can also be constructed (figure 2.4). The placement, design and dimensions of the hauler can vary according to the size and length of line, and the type and depth of fishing.

Traps and Pots

Traps are devices that fish or shellfish enter in search of shelter or food, or because an obstacle is placed in the fish's normal path of migration. They are designed so that getting out is harder than getting in. Traditional techniques employing traps and pots have developed in all regions of the world to catch demersal species. Their design and operation match the specific conditions and behavior of fish in a given area. Hence the importance of local knowledge in design and placement cannot be overemphasized.

Traps and pots can be quite specifically tailored to species and size. They may be constructed of local materials, generally at low cost, and usually require no bait. An additional advantage of this fishing method is the high quality of the live catch.

At the same time, their construction requires skill and knowledge of fishing conditions. Traps and pots are bulky and can occupy considerable space on a vessel. Handling is difficult, and manual hauling is arduous. A major disadvantage of this technique is the high loss of gear due to theft, storm damage, degradation of materials, and the inability to locate the gear once it is deployed.

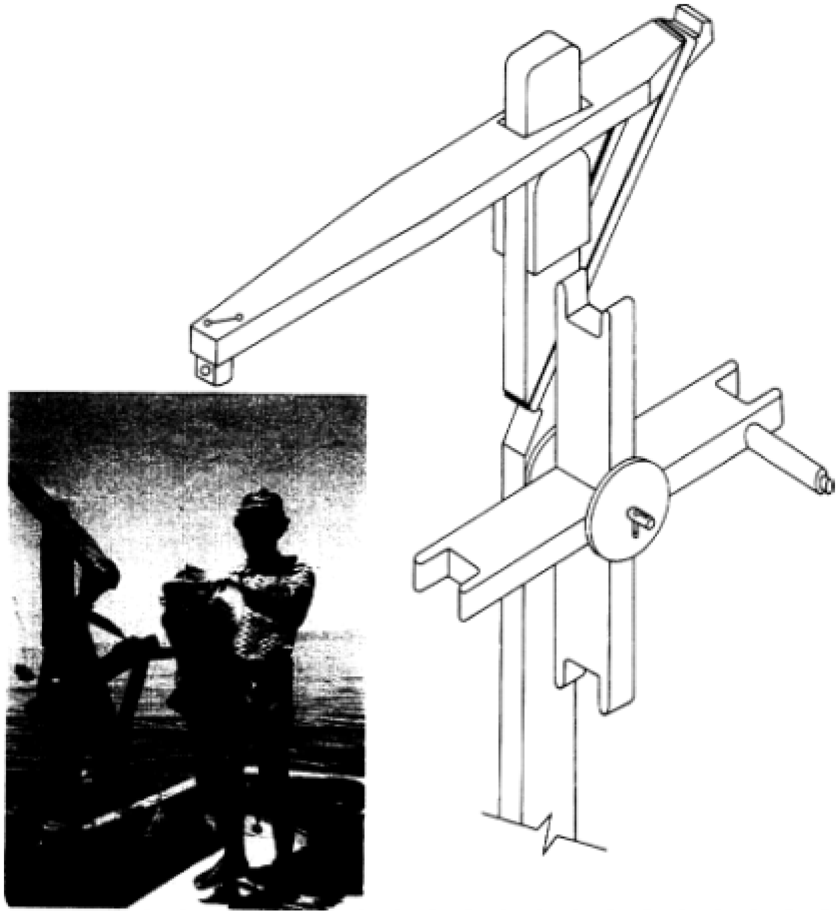

Figure 2.4
A simple wooden handreel can ease landing larger fish. (D. C. Cook)

A lost trap may continue to operate ("ghost fishing"), depleting marine resources.

Traps increasingly tend to be constructed of more durable materials, such as wire mesh and vinyl-clad wire netting, instead of traditional woods and fibers. Electrical, mechanical, and hydraulic hauling techniques are also modernizing this fishing system. There are thousands of trap designs throughout the world, many of which would be innovative outside of their region of use.

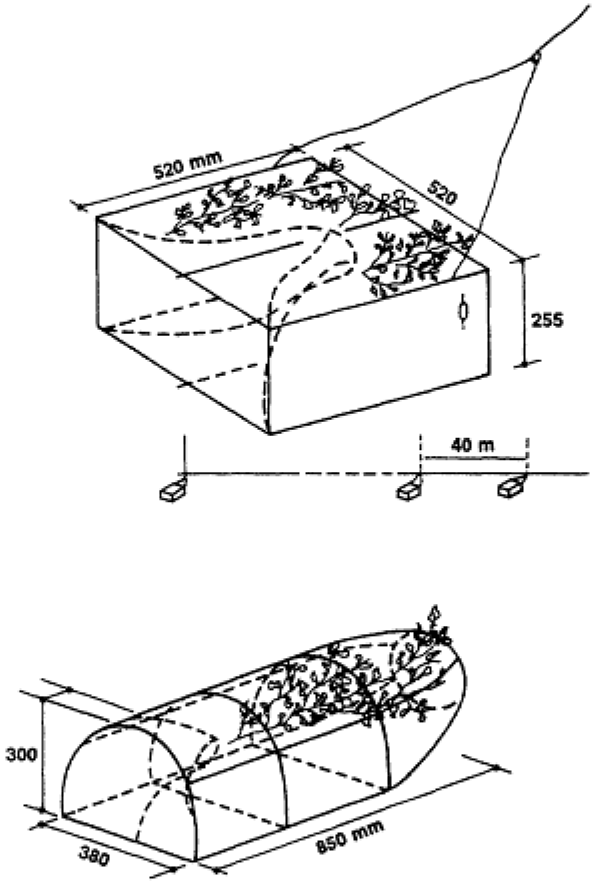

Figure 2.5
Cuban fishermen cover their crab traps with mangrove branches to provide a shady enticement. These traps are set in long rows, about 40 m apart.

The use of mangrove boughs to cover trap roofs provides attractive shade and shelter for some species. Cuban cylindrical or box crab traps, made of wire mesh, are lined with boughs and are set out in long rows of 50-60 traps, about 40 m apart (figure 2.5). The traps are checked every 2 or 3 days.

The "curiosity trap," used throughout the Caribbean, has curved surfaces, which seem to attract snapper, grouper, jack, and other bottom species. The trap is fished in sandy bottoms near reefs or rocks in water depths between 3 and 80 m and requires no bait. Made of wire netting, it has two funnel entries, which turn down. Since the trap measures approximately 2 × 3 × 1 m and has large funnel openings (11 × 20 cm), fish weighing up to 12 kg can enter. It is usually pulled and cleared every third day.

Variations of Caribbean Island fish traps incorporate exterior funnels leading into a cone-shaped interior funnel that is often turned down to prevent escape. These traps are generally rectangular, although they may be cylindrical or have pointed roofs. Traditionally, cane fibers were used in construction (figure 2.6), but marine mesh and galvanized chicken wire are increasingly popular. Fishermen report that such traps catch lobster as well as all types of bottom fish, such as snapper, grouper, and blue runner.

A trash can is used in Hawaii to catch deepwater shrimp. The bottom is cut out of a 10-gallon trash can and is replaced by a 3/4-inch nylon fishnet funnel, which is the only entry. A part of the lid is also cut out and replaced with a 1/2-inch wire mesh. This trap is light, economical, and obtains profitable catches.

Whippy bough traps catch fish by the elastic power of a bent bough. When the fish takes the bait, it releases a holding mechanism, which causes the rod to straighten and the catch to be suspended out of the water, clear of predators. This automatic fishing line is common in Java, Thailand, and Europe.

Octopus pots are artificial caves where these animals find refuge, but are free to leave at will. Earthenware pots with handles (Italy, Malta) or without handles (Japan, Korea), are strung singly or on longlines with up to 100 pieces. If the pots are hauled neck down, the octopuses will remain in their shelter.

Sections of PVC pipe are used by the Japanese as octopus pots. Two sections of pipe, 15 cm in diameter and 75 cm long, are attached side by side. A 5-cm cement plug bisects each section. This pot offers four dens for octopus and lies fiat on the bottom (figure 2.7).

An equally effective pot can be made from old tires. The tires are cut in thirds, the rims laced together with wire, and a circular wooden disk nailed to one end (figure 2.8). Tire pots have been fished extensively in Venezuela. These pots as well as the PVC pipe pots are fished from bottom longlines at intervals of about 8 m. Buoys mark both ends of the line so that the gear can be easily located and recovered after a fishing period of several days.

Timed-float releases or pop-ups can also be attached to the traps (figure 2.9). The pop-ups corrode in saltwater after a given number of days, and the increased rope length permits the previously submerged float to ascend to the surface. This allows concealed traps and reduces poaching, theft, or cut-off floats.

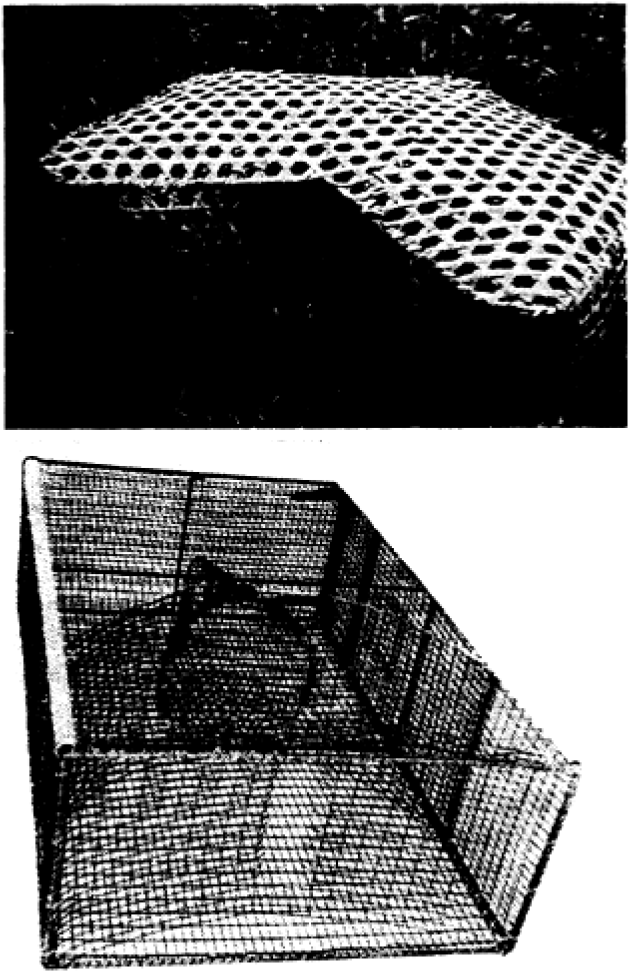

Figure 2.6
Traditional and commercial fish traps operate side by side in the Caribbean. The entry to the woven trap is at the top center (D. Suman). The metal trap is large enough (2.0 × 1.1 × 0.6 m) to hold 180 kg of fish. A. section of one of its panels is biodegradable to avoid "ghost fishing" if the trap is lost.

Corrosion is always a serious problem with metal traps. One solution is to use marine mesh, which combines the strength of

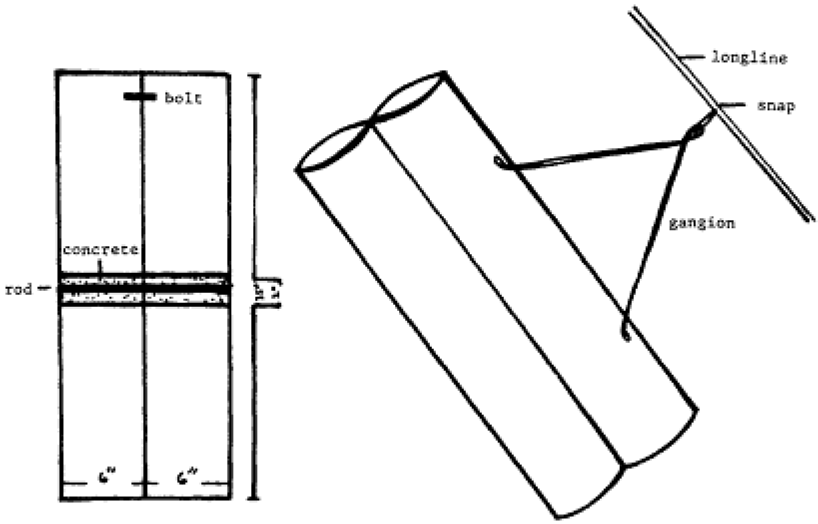

Figure 2.7
Sections of plastic pipe can be used as octopus pots. This design creates four chambers, each about 15 × 35 cm, by dividing two pipes in half with a concrete plug.

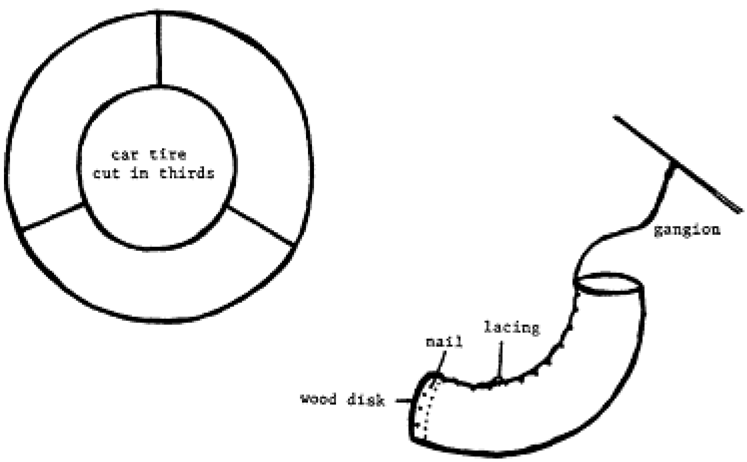

Figure 2.8
For use as octopus pots, discarded tires can be cut in thirds, laced into cylinders, and closed at one end with a wooden disc.

steel wire with the durability of plastic. The steel or galvanized wire is coated with polyvinyl chloride. Zinc or aluminum anodes can also be attached to metal traps to create a galvanic couple with the iron and double or triple the life of the wire netting. One of the disadvantages of traps is their bulkiness. Some collapsible traps made of wire mesh and plastic are commercially available, but there is a need for local research in this area.

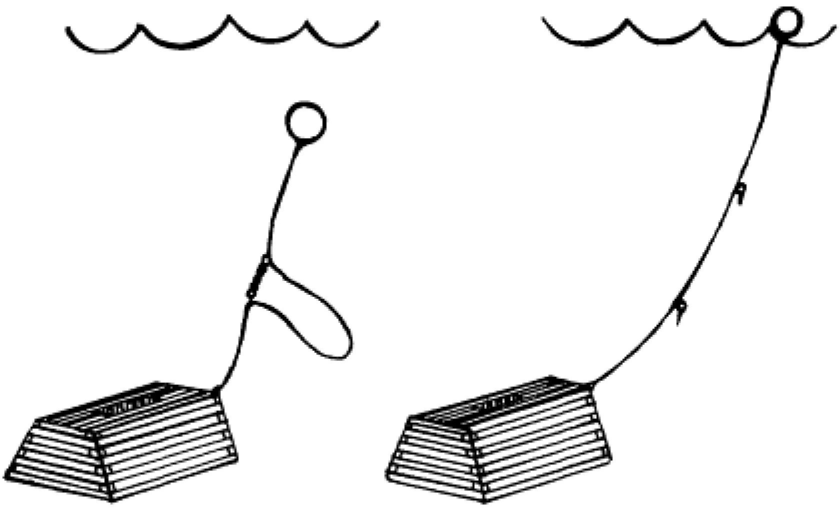

Figure 2.9
Seawater corrosion is put to good use with these timed Boat releases. The thickness of the corrodable band determines how long the marker float stays underwater. For example, traps set with a three-day band on Monday would stay unmarked until Thursday when the float would surface. In the interim, poaching, trap theft, and accidental cutting of the trap line would be reduced.

Weirs and Trap Nets

Large traps can be built in shallow coastal waters to capture sizable schools of fish such as salmon, bonito, tuna, herring, sardines, and cod. Leaders, or wings, guide fish through a slit and into a corral or catching chamber. The small opening acts as a retaining device so the fish do not escape from the corral. Unlike smaller nets, these large structures are not closed at the top. If the walls are constructed of non-textile materials, the trap is called a weir. Pound or trap nets utilize textile netting.

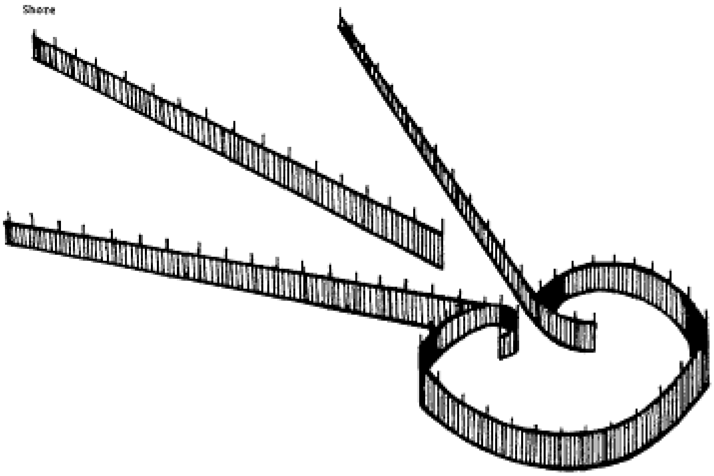

Figure 2.10
The bamboo stake trap is set facing the shore. As the title recedes, shore-feeding fish head for deeper water and the wings of the trap guide them to the center area where they are netted.

Weirs and trap nets have a number of advantages that favor their use in developing countries. They may be constructed of local materials and use little or no energy. Where seasonal runs occur, the catches can be enormous. Indeed, these traps are the only means to intercept large schools without a costly investment in vessels. The fish are live at capture, and therefore in excellent condition.

Nevertheless, if the construction material for the traps is netting, costs may be significant. In addition, a great deal of labor is needed to install these devices. These traps are limited to physically suitable areas and to local and seasonal fish behavior. Constant observation is required during the fishing season.

These traps show a tremendous diversity in design. Large bamboo weirs are used in Southeast Asia. The bamboo stake trap consists of long fences of split bamboo, fastened at intervals to large wooden poles driven into the shore bottom. Long wings guide the fish into the heart-shaped center of the trap where they are harvested with nets (figure 2.10). It is usually set with the open end toward shore.

In trap nets, the netting is usually hung from stakes driven into the bottom, although in deep water anchors and floats may be used. The bottom of the corrals may also be made of netting to facilitate harvesting the fish.

In the Caribbean, a simple trap net is used in shallow shelf areas (figure 2.11). The length of the wings depends upon the characteristics of the region, but generally the maximum placement depth is 4 m. One of the nylon mesh wings runs from the shore to the corral opening to intercept the migration path of the fish. The other wing is semicircular to prevent their escape and direct them into the corral. From the corral, a narrow opening leads into a smaller holding pool or crib with a net floor to make fish recovery easier.

A similar Caribbean trap net is used to capture crabs. The crabs enter the corral through a conical passageway. The lower and upper parts of the corral walls are made of zinc sheeting to prevent the crabs from escaping. This technique is reported to be extremely productive.

A Japanese floating trap (figure 2.12) is another variation on this theme. A floating net cage (25 × 8 × 4 m) is anchored over the shallow shelf. One wing extends up to hundreds of meters to the coast and the other to deeper waters. Schools of fish are again directed by the wings through the slits in the cage. Depending on its placement, this floating trap catches demersal as well as pelagic species.

Entangling Nets

Entangling nets are net walls, placed transversely to the path of migrating fish. The bottom of the net is weighted with sinkers while the top is supported by floats.

A single-walled net (gill net) is used to gill fish, while a triple-walled net (trammel) entangles them.

Gill Nets

A gill net is an upright wall of fiber netting. A fish, of a size for which the net is designed, swimming into the net, can only pass part way through a single mesh. As the fish struggles to free itself, the net twine slips in back of the gill. The fish is thus gilled and can go neither forward nor backward. Various mesh sizes are employed, depending on the species and size of the fish to be caught (figure 2.13).

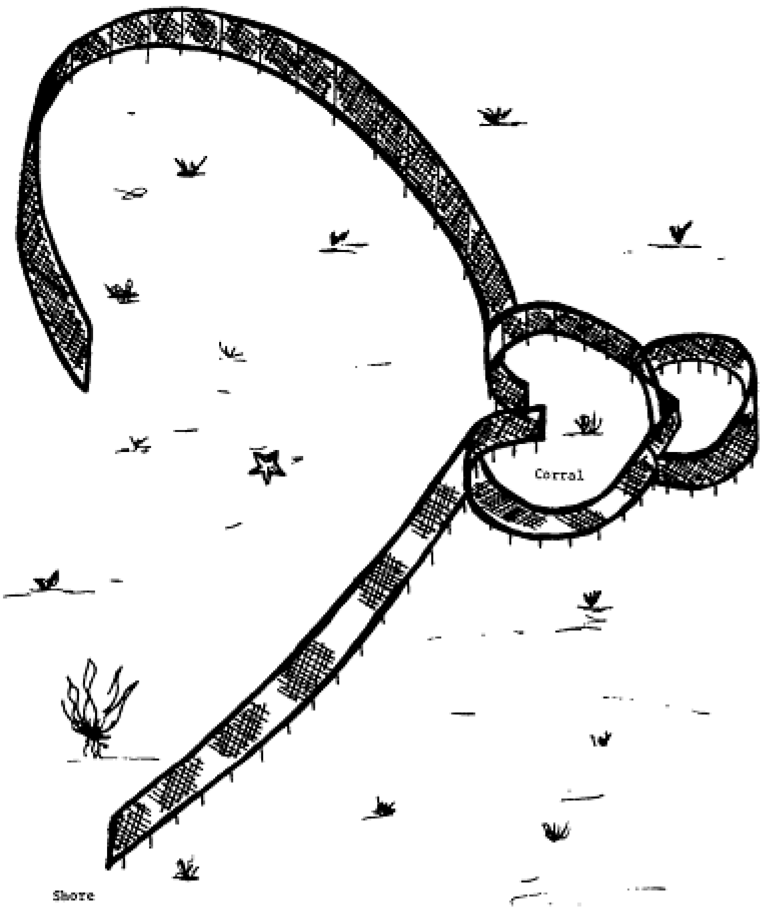

Figure 2.11
This Caribbean trap net is set to capture fish swimming parallel to the shore. One wing of netting extends from the shore to the corral and the second is placed in a semicircle to deflect escaping fish.

Trammel Nets

Trammel nets have three panels of netting suspended from a common row of floats and attached to a single bottom line. The two outside walls of netting have a mesh larger than the targeted fish, and the interior netting has a smaller mesh size. The inside net hangs loosely between the two outer nets. A fish striking from either side passes through the large mesh outer panel, strikes the smaller mesh interior panel, and carries it through the opposite large mesh panel, forming a sack or pocket in which the fish is trapped (figure 2.14). A trammel net is often fished by drifting.

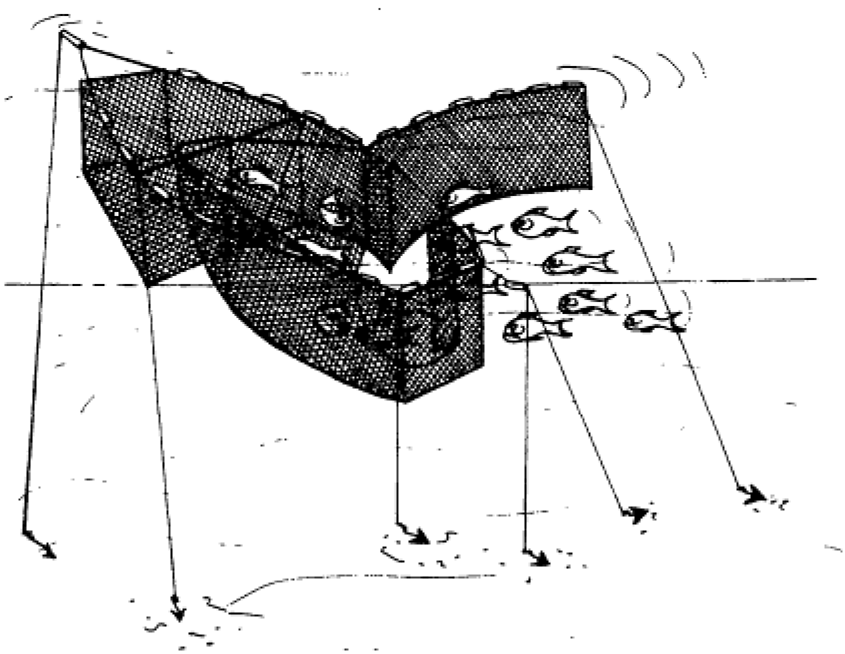

Figure 2.12
A Japanese floating trap is anchored in shallow water. Schools of fish are intercepted and diverted into a net cage.

These nets may be used at the surface, in midwater, or at the bottom (figure 2.15). Although a single net may be deployed, usually a row of nets are set. A fisherman may choose to anchor his net or allow it to drift. In intertidal areas, the nets may be driven into the bottom and the fish collected at low tide. Taiwanese fishermen tie scare ropes around their bodies and swim as a group toward a fixed net. Fish in the swimmers' path are frightened into the net.

To be most effectives a net should be invisible to the fish. In the past, cotton nets were dyed different colors to match the background. Nowadays, transparent monofilament nets are mainly used for entangling nets, though more visible but softer continuous-filament nylon nets are still popular in some fisheries.

Monofilament fibers are less elastic and stiffer than continuous multifilament nylon fibers. Thus, although the former are more efficient in catching the fish, the latter hold them better.

The great advantage of entangling nets is their selectivity. The way the net is hung and its depth determine the species of fish captured. The shape and size of the mesh also select fish species

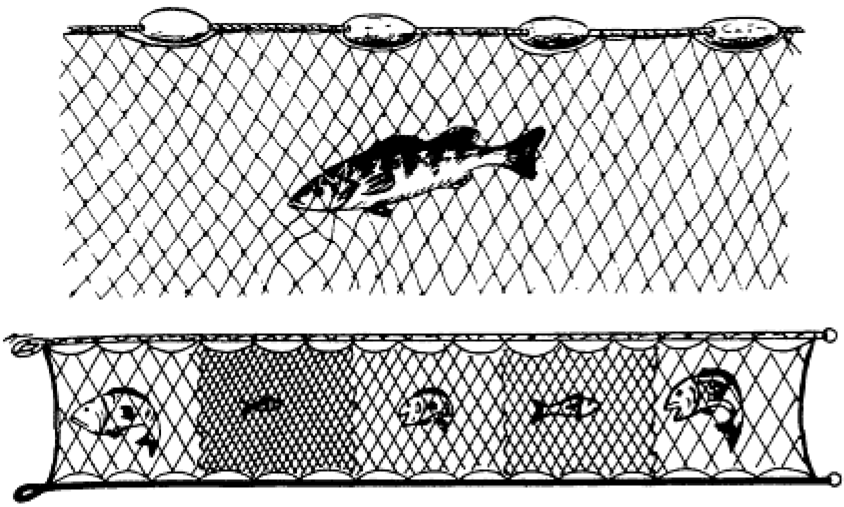

Figure 2.13
The mesh size of a gill net determines the size of the fish caught.

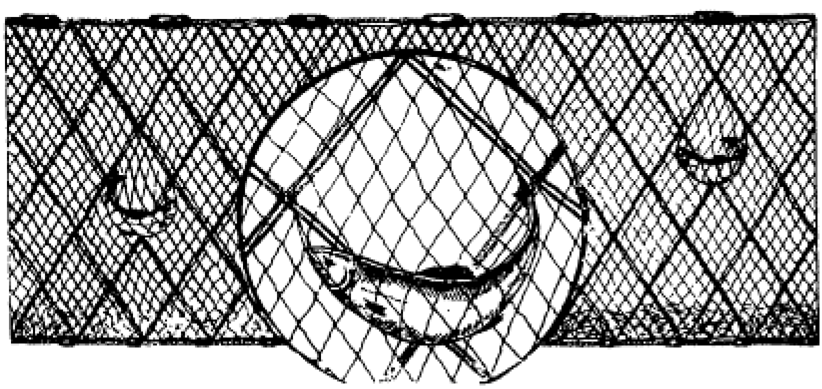

Figure 2.14
Trammel nets capture fish in a pocket of netting.

of a specific size. Fish whose girth is smaller than that of the mesh opening are able to swim through.

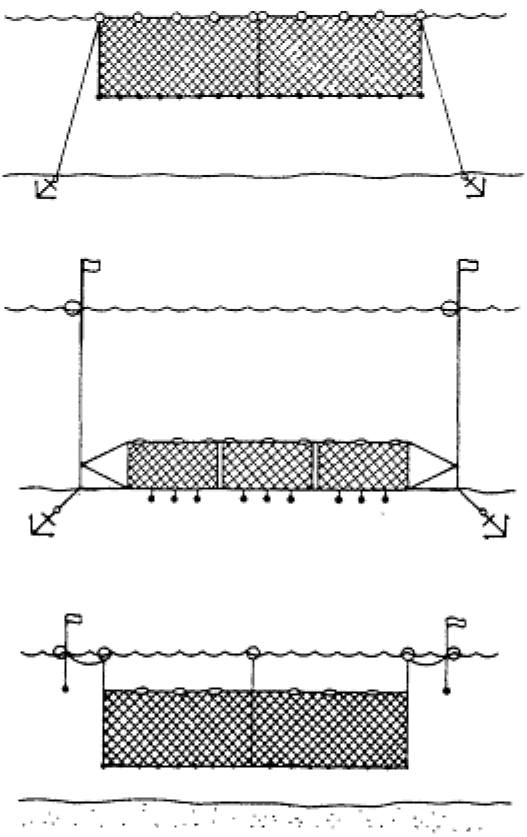

Figure 2.15
Entangling nets can be used at the surface, midwater, or on the bottom, either anchored or free-floating, depending on the target fish.

Even a lone fisherman can manually deploy a gill net or a trammel net from a small craft. Floats and sinkers can be made of local materials such as bamboo, bottles, cement, or stones, although manufactured equipment might be more efficient.

These advantages are balanced by serious liabilities. Entangling nets cost more than hooks or traps. They require a high degree of maintenance, and picking the fish out of the net is labor intensive. Since the fish are usually dead when harvested, they will be of lower quality.

Ghost fishing with nets made of synthetic fibers is a problem.

If lost, the nets continue to trap fish, because the fibers are not biodegradable. To avoid this, the twine holding the netting to the floats should be made of natural fibers, which will rot in time.

Stationary Liftnets

Liftnets are lifted from the water at the moment when the sought-after fish have gathered over them. These nets can be installed on boats or on the shores of rivers, lakes, lagoons, and estuaries (figure 2.16). Lifting power may be provided by pulleys or weighted levers.

In South India, liftnets are operated off the beaches and lifted with counterweights. At night, lamps are hung from the crossbars to attract fish.

Light is also used to attract fish to liftnets operated from shipboard. In the Caspian Sea, Soviet fishermen use small circular liftnets equipped with underwater electric lamps to catch anchovy. A larger variation of liftnet is called a blanket net. Operated from the ship's side, it can almost be as wide as the vessel's length (figure 2.17). Four-boat liftnets are common in Scandinavian and Southeast Asian fisheries. The net is lowered or raised by all the boats in unison.

The Lake Tanganyika liftnet is suspended from hauling ropes at the four ends of a catamaran 3.35-6.0 m long. The net is shaped like an inverted pyramid and has a stretched depth of 12 m. Kerosene lamps are used to attract the fish over the net

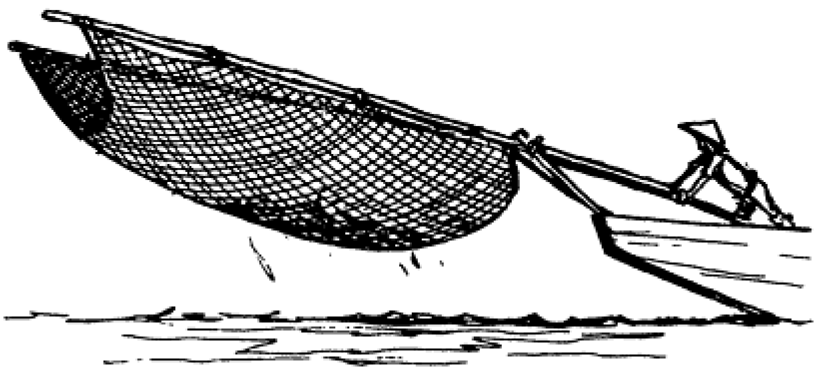

Figure 2.16
Liftnets can Be used from small Boats or from the shore. Fishermen Bait the net area and wait for fish to gather. At night, torches or lamps can Be used to attract fish.

opening that is suspended between the two hulls. After the fish have been concentrated, the net is quickly hauled through the open area between the hulls.

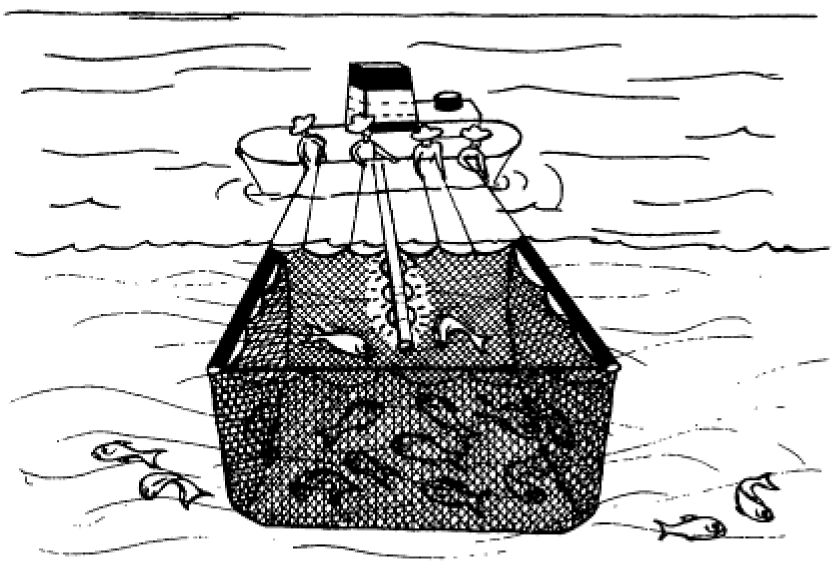

Figure 2.17
On larger boats, electric lights are used with liftnets to capture anchovies and sardines.

Liftnets can be cost effective and labor effective when set under specific conditions (narrow passages and rivers) or when attracting fish with chum or light. The catch is alive and, therefore, of good quality.

This fishing technique, especially in combination with light attraction, could be used in many areas, either for consumable fish or live bait.

ACTIVE GEAR

Active gear has to be moved, dragged, or towed in order to capture fish. This usually requires engine-propelled boats and usually involves additional investment over passive or stationary gear.

Trolling

Trolling lines are simple hooked lines that are trailed from a moving vessel at a controlled depth. Bait may be artificial or natural and attracts predator fish that see what appears to be a smaller fish thrashing and turning in the water. The lure may be nothing more than a colorful piece of cloth, a small bunch of feathers, or a piece of skin from the bait fish, but it must be carefully adapted to local conditions and fish species and size. The use of outriggers can increase the number of lines that can be trolled and helps keep them from becoming tangled.

Trolling offers numerous advantages to small-scale fisheries. Multiple trolling can be performed from a reasonably small craft. Changing sinker weights allows fishing at graduated depths. Lures can be made of local materials and easily changed for the target species. The use of artificial bait avoids the capture or purchase of live bait.

Trolling is also an excellent auxiliary method and can be used as the vessel is going to or returning from other fishing grounds (figure 2.18). Eligible areas include inshore or offshore waters, and target species may be pelagic or demersal. The introduction of trolling does not require high skills or a large investment in gear. Little labor is necessary in this fishing art. Sails are an ideal form of propulsion for this fishing method.

A number of innovations can make trolling more efficient and save labor. Simple hand and electric reels can make work easier and allow more fish to be caught in a given time.

Large and small umbrella rigs permit the fishermen to have several hooks on a trolling line. For many species umbrella rigs are more attractive than conventional lures, perhaps because the

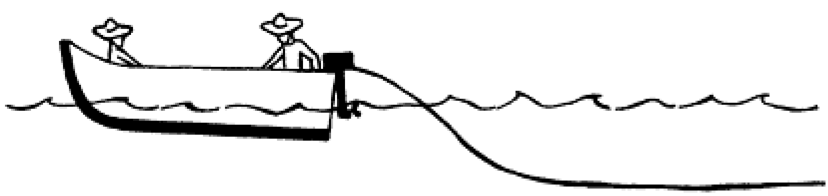

Figure 2.18
Additional fish can Be caught By trolling between the fishing grounds and landing. The fishing depth can be adjusted by changing sinker weights.

multiple lures create the illusion of a school of fish. The number of lines a vessel can troll can also be increased by towing two smaller boats to spread the lines over a larger area (figure 2.19).

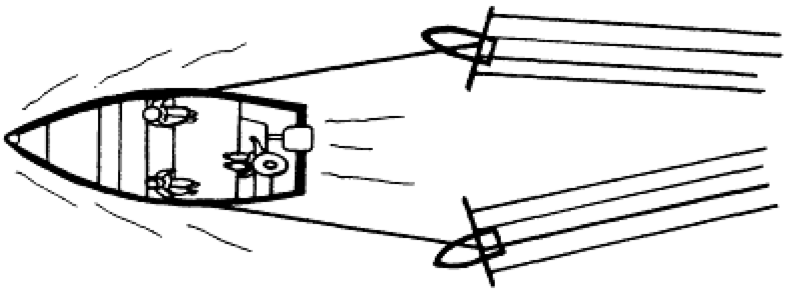

Figure 2.19
Multiple trolling lines can be used if poles, floats, or small boats are used to spread the lines.

Depressors are used by Japanese fishermen for midwater trolling. These are flat, small boards weighted with lead at the front edge. The depressor itself is towed by a line attached near its front edge. Besides submerging the line, the board also wobbles, so that the hook jumps or jigs. When a fish takes the hook, the board tilts and rises to the surface.

Another trolling variation, the fish kite, is popular in Micronesia, Melanesia, and Indonesia. The kite is flown up to 100 m behind the boat, and its tail line carries a ball of cotton or a piece of sharkskin as bait. The kite is maneuvered so that the bait continuously bobs on the surface of the water and induces garfish to snap at it.

Jigging

The jigging technique involves mainly catching fish by impaling them with special hooks. In jigging, the line must be jerked to pierce the fish. Generally, the sharp hooks are weighted so that when they are pulled up, there will be sufficient momentum to penetrate the fish. In some cases, regular baited hooks are jigged manually or mechanically to attract attention to the bait. Special reels can be used to impart a jigging action to the line (figure 2.20).

Rippers or jigs are especially used to catch slow-moving fish that are spawning. They are also widely used throughout marine fisheries. The Norwegian Juksa-line catches cod by jigging, and the Turks jig for bluefish in the Bosporus. Special hooks are used in east Asia and the Mediterranean to jig squid. The potential exists for significant expansion of squid jigging by light attraction.

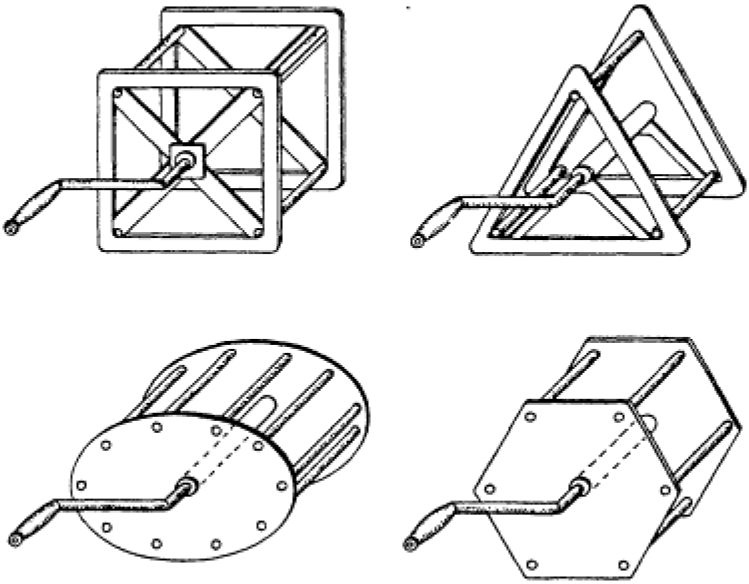

Figure 2.20
Specially designed reels can give a jerking action to lines as they are hauled; they improve results in jigging.

Jigging is a low-cost, low-energy technique that does not require bait. The live catch is easily brought into the boat. At the same time, it is labor intensive and time consuming, unless relatively expensive jigging machines are employed. Jigging requires knowledge of the local area to determine where and when it can be used.

Seining

Seines are long nets with meshes small enough to prevent the desired fish from gilling (filtering nets). They are generally set in a semicircle and dragged over a smooth bottom by means of long ropes (sweeps). In this way, the fish are herded into the net and hauled onto the beach or on board.

Beach Seines

Beach seines are especially appropriate for catching seasonal pelagic species as they feed near shore. They are most often set from the boat. One end remains on shore, while the rest of the net is set in a curved path and brought back to the beach (figure 2.21).

Once the second drag line is delivered to shore, the hauling begins. The bottom and water surface act as natural barriers for the fish encircled in the net. The wings may often be hundreds of meters long.

Large beach seines, however, are costly, and their use is restricted to large stretches of smooth, shallow bottoms with fairly mild surf. The net is species-indiscriminate and may catch juveniles of large-sized fish. Small two-man beach seines are often used for catching live bait or small fish (figure 2.22). These tend to have a uniform small mesh.

Beach seines have the potential for increased motorization and mechanization. Shore-anchored pulleys, tractors, jeeps, or even animals could be used to make hauling easier.

Boat Seines

Boat seines are set and hauled from a boat. A vessel anchors one end of the seine and sails in a circle, releasing the net, and returns to the anchor. The net is then hauled into the boat (figure 2.23).

With small seines, this fishing technique can be used by smaller vessels without mechanization almost anywhere there is a smooth bottom (figure 2.24). The high skill involved in net design and the cost of its construction are liabilities.

Boat seines have the potential of bringing small-scale fishermen to previously unexploited resources. However, any introduction of modern technologies (motorization of the boat, rope and net haulers, storage of nets and cables on reels) that would enlarge the area covered and could increase the catch, involves capital investment and an increase in running costs.

Purse Seines and Ring Nets

Purse seines are characterized by a line at the bottom of the net that is used to close off this escape route (figure 2.25).

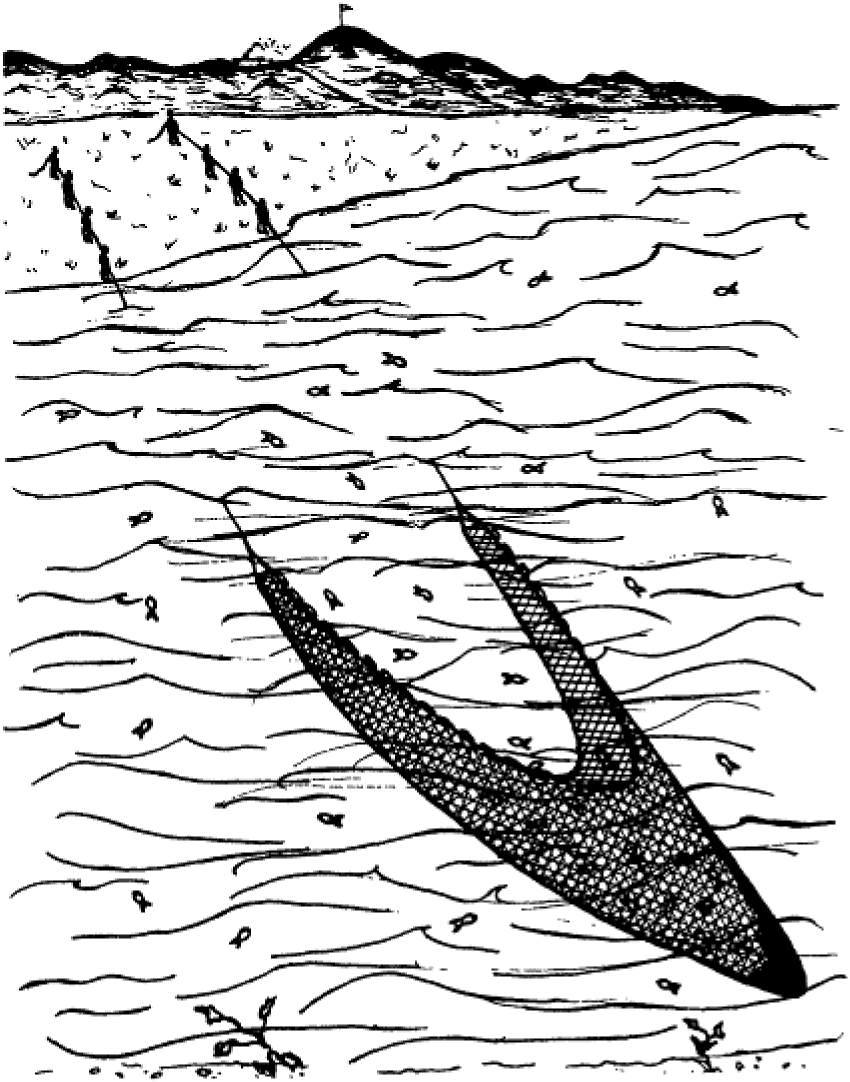

Figure 2.21
Using large beach seines is a group effort. One end is held on the beach while the other is rowed in a curve back to the beach and hauled in.

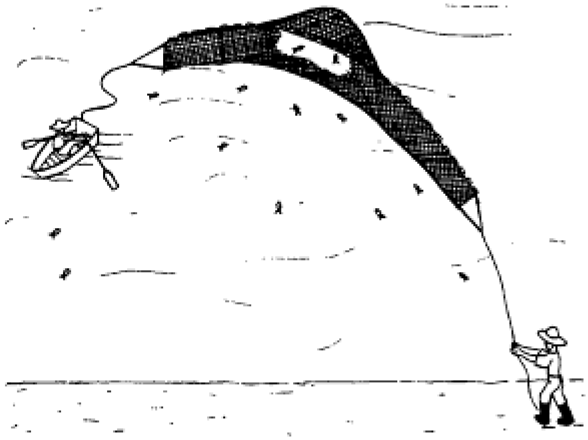

Figure 2.22
Smaller beach seines can be a two-person operation, useful for catching bait fish.

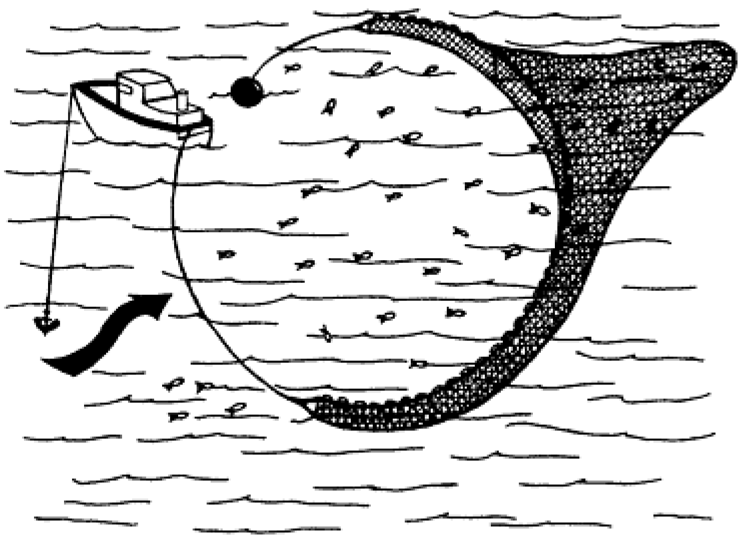

Figure 2.23
Large boat seines are used by anchoring one end of the seine, sailing in a circle back to the anchor point, and hauling the net.

The purse seine can be set with one or two boats and must be fished quickly. Those that are operated with two boats are called ring nets. Light may also be used to attract the target species.

Purse seines are highly mobile and can capture whole large schools of pelagic species that gill nets and beach seines could not. Hauling can be done manually, and the catch is live.

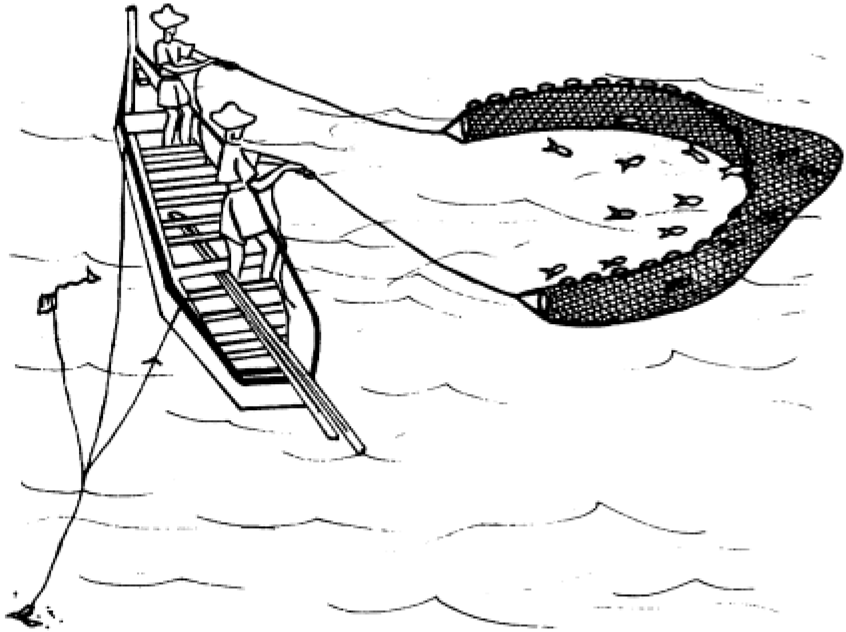

Figure 2.24
Small Boat seines can Be handled By two fishermen without mechanization.

Nevertheless, purse seines are costly and require highly skilled operators. Purse seining with two boats (ring netting) enables small, artisanal fishing craft to take advantage of this method (figure 2.26).

Bottom Trawling

Trawls may be towed behind one or two boats or, in shallow waters, even dragged by a fisherman (figure 2.27). Trawl nets generally have a cone-shaped body with a wide opening between two wings. In bottom trawling, the net is towed on the bottom in order to capture shrimp and demersal fish.

Pair Trawling

Pair trawling uses two small boats to tow the trawl, one on each side (figure 2.28). Having two boats keeps the trawl net open. This method also permits Boats with small (5 hp) engines to trawl and allows small-scale fishermen to compete with larger trawlers.

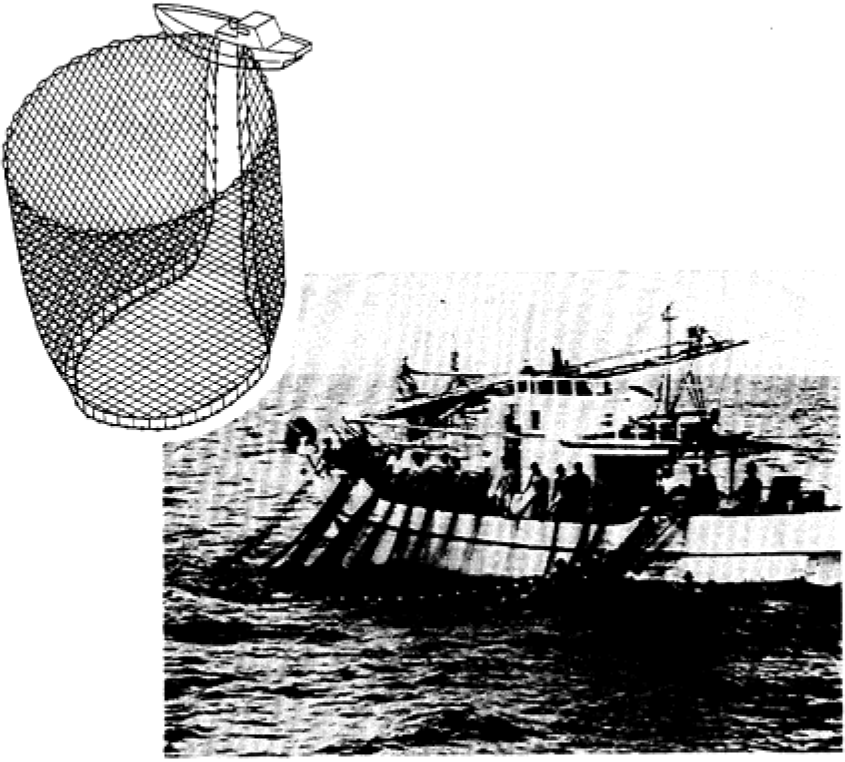

Figure 2.25
Purse seines have a line at their bottom edge that can be drawn to close off the base of the net. (FAO photo)

With the same total horsepower, more fish can be caught with pair trawling than if a single Boat tows the net. Whereas the noise from a single engine directly in front of the trawl net can frighten fish from the path of the net, the noise from two engines on either side of the opening will scare some fish towards the center, directly into the net.

Pair trawling has limitations. Two boats must cooperate and work as a team. The fishing area is limited to smooth bottoms. Even in ideal areas, the net can be damaged or lost on a wreck or a rock.

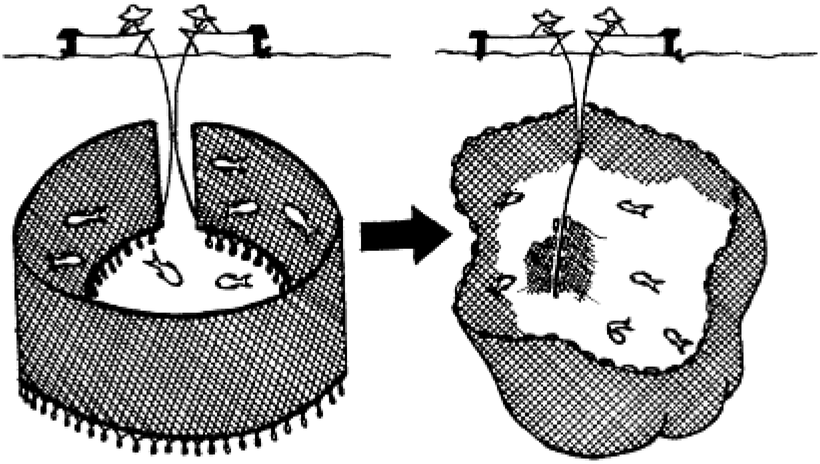

Figure 2.26
Purse seining with two boats (ring netting) allows smaller boats to use this technique

The value of the catch must be at least equal to the sum of the value of the two vessels' catches if they fished alone.

If the boats have engines stronger than 8 hp, they are strong enough to tow sweeplines. These lines are made of heavy rope and are towed on the bottom in front of the wings of the trawl net. They serve to scare fish from a wider area into the net.

Single Boat Trawling

A single vessel with an adequate power source may also tow a trawl, but otter boards or a beam are required to open the net horizontally.

Beam trawls are the simplest trawls and are used primarily to capture flatfish and shrimp (figure 2.29). The horizontal opening for these nets is provided by a beam made of wood or metal that can measure up to 10 m in length.

Smaller beams, about 2 m in length, are used with rowboats in Portuguese rivers. Although small beam trawls might be used by artisanal fishermen, they obviously lack the fishing spread of larger trawls, which require power and mechanization.

Otter trawling is a more complex fishing system. These trawling nets have their horizontal opening maintained by the shearing action of the heavy otter boards (figure 2.30). Demersal or pelagic species can be captured by this fishing method in shallow waters.

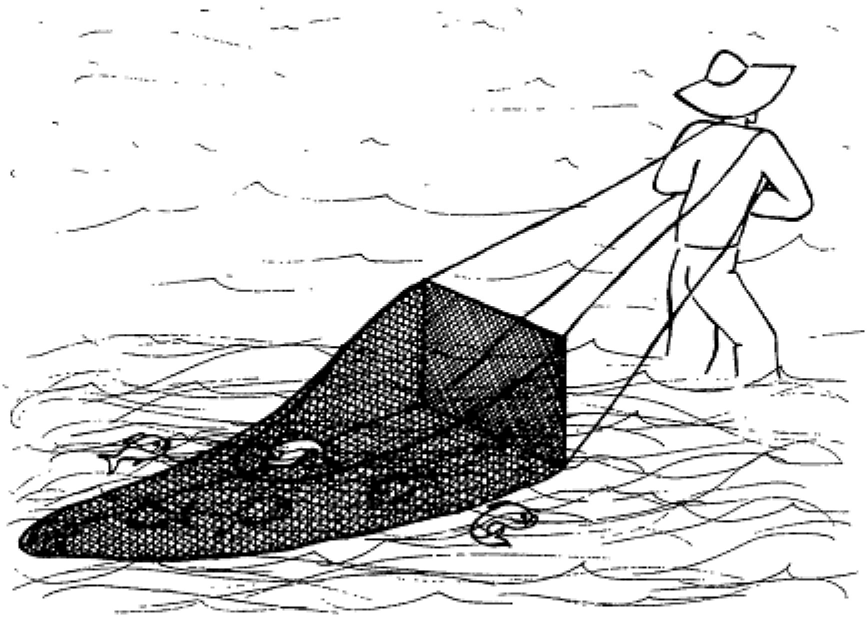

Figure 2.27
Trawl nets can be pulled by one or two boats or, in shallow water, dragged by a fisherman.

Otter trawling gives fishermen broad access to marine resources. But the high costs, large energy requirements, and the specialized skills required to maintain the equipment and use it effectively make it feasible for small-scale fisheries only under very favorable conditions. The minimum power for an otter trawling boat is 30-40 hp with a relatively high gear ratio (low propeller rpm) and a large propeller diameter to provide maximum towing power.

Electronic Equipment

Much marine electronic equipment was initially developed for military use in communications, navigation, and underwater reconnaissance during World War II. Postwar growth in the electronics industry resulted in lower costs for this type of equipment and ocean-going fishermen began to use it. As costs decreased

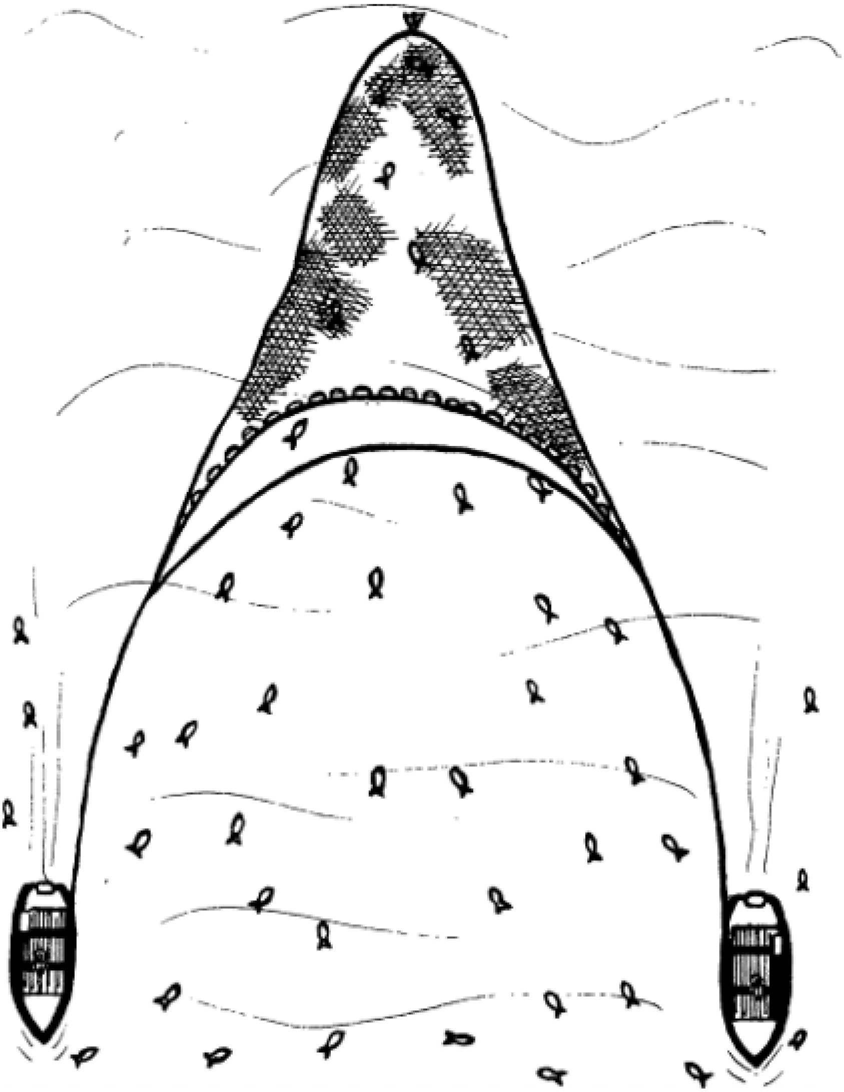

Figure 2.28
Boats without enough power to trawl singly can often trawl in pairs. Using two boats allows a wider area to be covered and makes it easier to keep the net open.

even more, the market has broadened to include smaller-scale commercial and sport fishermen.

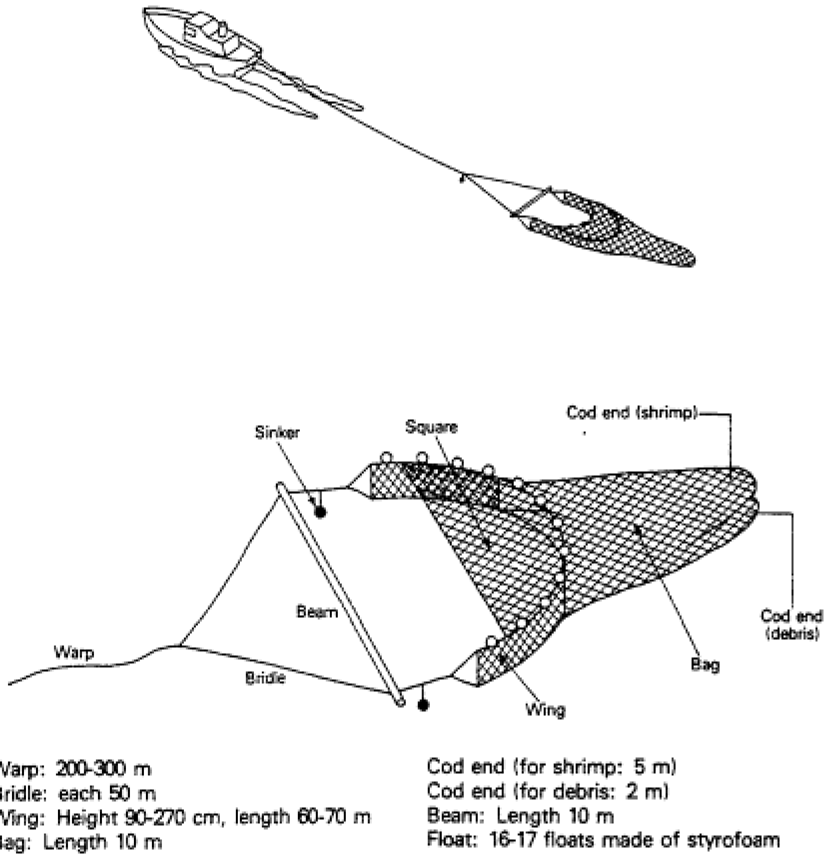

Figure 2.29
Beam trawling is accomplished from a single boat. An 8-to 10-m pole (beam) is used to keep the net open horizontally to capture flatfish or shrimp.

Although probably still beyond the reach of most individual fishermen in developing countries, some of this equipment may be cost effective for shared use in villages or cooperatives.

Perhaps the most useful for nearshore fishermen would be aids to fish location. The simplest of these is an electronic thermometer. Seawater temperature can markedly affect fish-feeding habits, and in thermally stratified water, species may concentrate at depths based on temperature. In addition to the value of knowing absolute temperature and its relationship to fish feeding and depth, changes in temperature are also important. Seawater temperature can remain constant over a wide area; a change of a degree or even less can indicate an upwelling or current boundary where fish may cluster. Stem thermometers that rely on liquid or metal expansion and contraction for temperature readings are not responsive enough for this application. Simple digital readout electronic thermometers can display instantaneous temperature changes of tenths of a degree. These are available for less than $100.

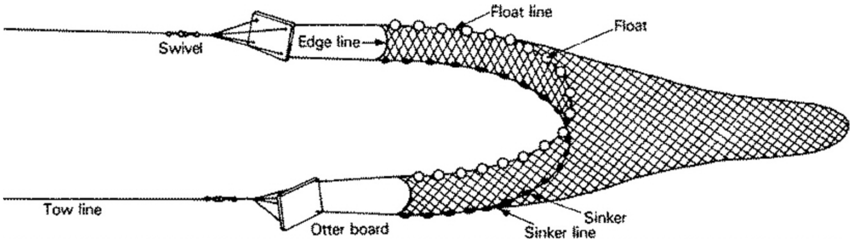

Figure 2.30
In otter trawling, two fiat (otter) Boards are used at either end of the net to hold it open.

Another valuable device is an electronic depth recorder. These can indicate water depth, bottom formations, and fish locations. Boats need travel no farther than is necessary to detect fish. Nets and lines can be set and hauled with greater efficiency. Rocky bottoms potentially damaging to trawls can be detected. The results of a properly used depth recorder can be dramatic and should have a direct and visible economic benefit. To use this equipment, a fisherman must install a transducer on the hull. A method of installing this unit on temporary brackets has been developed to allow its ready transfer from vessel to vessel. Costs for these echo sounders range from $200 to $600.

Although excellent Loran and satellite electronic navigation aids are available, their costs are prohibitive. Where appropriate radio stations operate, inexpensive radio direction finders can be used to plot positions and plan courses.

LIMITATIONS

The introduction of fishing gear and methods to an area, whether these methods are technically new or simply new to a given region, is not without dangers.

Gear and methods are highly site specific. The fishing arts that have developed in a region are usually the best suited for the species and size desired, the given marine conditions, and the community's economy and structure. New methods may often be inappropriate and rejected by local fishermen.

Introduced gear may be too costly for the local economy to sustain. What appears to be economical to an outside observer is often impossibly expensive for the fishing community unless increased credit is made available. Innovations should be tested on a pilot scale to ensure that they are economically viable.

Many coastal waters are overfished. Upgrading the gear and making it more efficient increases the risk of depleting the fishing stocks even more. Therefore, the introduction of any new gear or methods must be accompanied by proper monitoring and protection of the marine resources.

More sophisticated fishing arts may require training for the fishermen. At the same time, modifications in gear may necessitate simultaneous improvements in the design, power, and size of fishing vessels.

Almost all marine electronic equipment requires 12 volts DC to operate, although current requirements are fairly low, less than 10 amps. Because most of this equipment is not designed for user repair, maintenance is a more severe problem. The most practical approach is to minimize the number of different models in use.

RESEARCH NEEDS

A persistent concern when introducing new gear or methods is that of exceeding sustainable fishing yields, thereby making the fisherman's lot temporarily better but ultimately worse. Research on simple methods for determining fish populations and their regenerative capacity could be very valuable. New gear or methods could then be used without fear of overfishing.

In situations where specific gear is potentially valuable but too costly for a fishing community, adaptive research on local manufacture using local materials could be an alternative.

More information on combinations of attraction and capture methods is needed. The use of fish-aggregating devices (chapter 3) or light in conjunction with complementary traps or nets could improve the catch of specific sizes or species.

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3

Artificial Reefs and Fish Aggregating Devices

Experienced fishermen realize that fishing is often better in the vicinity of submerged objects such as rock outcroppings, shipwrecks, reefs, and logs, than in areas where the bottom is flat and barren. Many fish are attracted to the submerged objects on which marine plants and animals may grow. These communities serve as a basis for a marine food chain that provides food for larger predators. Submerged objects also provide shelter and spawning grounds for some fish and invertebrates (figure 3.1).

Artificial reefs are man-made or natural objects specifically placed to attract fish, provide or improve fish or shellfish habitat, and increase fish biomass locally. Extremes range from traditional designs frequently made from local scrap materials to modern Japanese-style artificial reefs that are highly sophisticated modules built of concrete, fiberglass, or steel.

The extent to which artificial reefs increase fish biomass or redistribute existing stocks of fish is not clear. However, even if they do not substantially increase fish production, they can be used as effective fisheries management tools. The increased standing fish crop around artificial reefs reduces fishing effort and, therefore, saves time and fuel. Fishermen in developing countries often must limit their efforts because of high fuel costs. Furthermore, artificial reefs can be used to create fishing grounds for artisanal fishermen who use traps and hook and line gear.

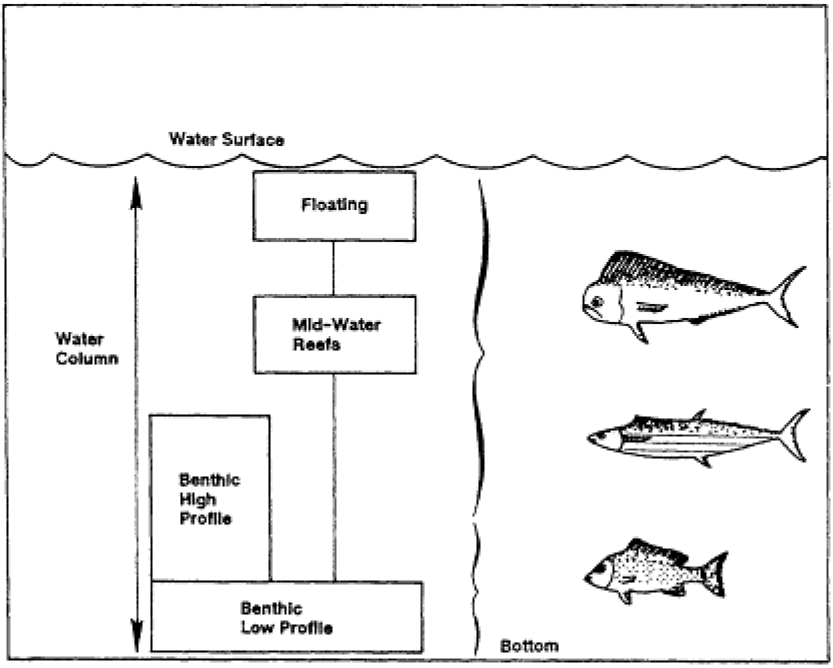


Figure 3.1
Depending on the marine environment and the target fish, high- or low-profile benthic reefs, or floating or midwater fish aggregating devices may Be used to attract fish and facilitate their capture. (J. McGurrin, Artificial Reef Development Center)

Fish aggregating devices (FADs) are structures located at the surface or at midwater depths to take advantage of the attraction of pelagic fish to floating objects. FADs called *payaos* have been utilized for centuries in the Philippines to attract migrating tuna. Like artificial reefs, FADs can also reduce fishing effort and conserve fuel.

ARTIFICIAL REEFS

Many types of fish live around reefs, plants, and corals. Artificial reefs function like natural reefs providing shelter, spawning, and nursery areas for reef fishes. Additionally, the algae and invertebrates that rapidly colonize the submerged structures provide a food source for some species.

Two approaches are possible for an artificial reef program, depending on available resources. Commonly available materials can be used for reef construction where funding is limited. Even these materials must be prepared to withstand extreme weather conditions, however. The second approach is to fabricate specially designed, essentially permanent, structures. This usually requires well-funded programs, steel and concrete for construction, and large vessels for placement.

The U.S. National Artificial Reef Plan provides general guidelines for the placement of artificial reefs. If possible, the site should be near fishing villages to simplify the logistics of installation and to minimize time, travel, and fuel consumption before the fish can be processed on land. An artificial reef should not be placed in commercial fishing areas unless it is specifically intended to close an area to these operations.

Recent research suggests that the reef site is more important than the design. The artificial reef should be located at least 6001,000 m from natural reefs; otherwise, the fish will tend to swim from one to the other. Sites with strong tidal currents should also be avoided because these currents will cause erosion around the reef, unless the bottom is hard. Mouths of rivers where siltation may bury the reef should also be avoided. A constant current is quite acceptable and is favorable to benthic filter feeders inhabiting the structures. The long axis of the reef should be perpendicular to the prevailing current and along fish migratory patterns. The depth of the reef must be appropriate for the target species.

A firm sand or shell bottom is most suitable for an artificial reef to prevent subsidence. The bottom profile should be fiat or gently sloping. Soft clay, silt sediments, and areas that are already biologically productive should be avoided. High wave energy locations and areas with seasonally shifting sands should not be considered.

The Japanese national program suggests that artificial reefs should have a hierarchal arrangement where modules form sets, 10-20 sets form a group, and several groups form a reef complex. They advocate minimum effective sizes of 400 m^3 for a set and 50,000 m^3 for a group, with at least a 1-km separation between each group. This approach in developing countries would be far beyond the means of artisanal fishermen; it would require strong national assistance.

Many locally available materials can be effectively used as artificial reefs. They should provide an appropriate habitat, be structurally sound, and firmly secured to the Bottom. The actual choice of material will be based on what is readily available and economically feasible. Bamboo, rattan, and stone are typical materials that have been used.

Bundles of Brush

In all areas of the world, fishermen have used simple bundles of brush to attract fish into hiding places and thus facilitate the catch. Bundles of brushwood are tied to lines to capture crabs, shrimp, and small fish in Japan, the Philippines, Indonesia, and Vietnam. The fish are harvested by shaking out the bundle into a scoop net.

In Central Africa, Boxes full of leaves are placed on lake or estuary bottoms. Fishermen lift the boxes out of the water and shake them to collect the small fish.

Ivory Coast fishermen place coconut palm fronds in shallow water to attract shrimp. While one person drags the frond to shore, another follows with a scoop net and gathers the fleeing shrimp.

In the protected areas inside the keys on the south coast of Cuba, fishermen are still using "mangrove fisheries." These structures are located in 4-5 m of water, usually in sea grass (*Thallasia*) beds. To build these structures, one needs a notched tree trunk about 1 m tall, two smaller branches nailed transversely, and a bundle of mangrove boughs, 4-5 m long, whose ends are placed into the two openings of the tree trunk. The bundle may have a diameter of almost 5 m and a height of 3 m. The structure may be fished about 15 days after installation and, thereafter, at intervals of 15-45 days. It usually lasts about 10-12 months. One small boat may fish up to 150 mangrove fisheries.

Brush Patios

In the Philippines, SEATI (Samar Sea-Ticao Pass Fisheries Development Corporation) has developed several "brush parks" to provide shelter and spawning areas for fish. Each unit in the park is a tripod made of ipil-ipil wood (*Leucaena leucocephala*, a fast-growing tropical tree). The tripods stand about 3.5-5.0 m tall. Horizontal crossbeams lashed on with nylon twine hold the tripod together. Villagers hang fallen coconut palm fronds from the horizontal beams. The units are placed in calm, shallow coastal waters and are held down with stones. The palm fronds have a useful life of about 3 months while the frames last about a year.

Preliminary results from SEATI indicate that a 6-month harvest of the brush units with nets yields between 10 and 20 kg of fish per unit. Croaker, squid, rabbit fish, barracuda, and anchovy are among the species caught. The algal and invertebrate growth on the structures is a food source for many species of fish. Others enjoy the safety of the structure's interior.

A brush park near San Jacinto Island, Masbate Province, Philippines, includes about 4,000 units. A trap net, constructed of bamboo, has been built in the center of this underwater forest. The final section of the trap net is regularly hauled. The undersized catch is returned to the sea to avoid depletion of the stock.

Lobster Shelters

Lobsters prefer a living space only slightly larger than the size of their bodies. Traditional Cuban artificial reefs have been developed based on this behavior.

The shelters are usually constructed of mangrove branches that are about 8-12 cm in diameter. The two thickest sticks are placed parallel to each other at a distance of 1.5-1.8 m. Two other parallel branches are placed above and transversely to the first layer. The two layers are nailed together or fastened with galvanized wire. A third layer or roof of branches is added to the structure. These additional pieces of wood are fastened to the second layer with some space between branches so that light can enter. Another level may also be added. The finished sandwich structure measures about 2-2.5 m on a side (figure 3.2).

These lobster shelters are used in shallow waters (4-6 m) that do not have strong currents. The number of shelters occupied is high, especially when the structure has been in the water for some time and supports algal communities. Shelters must be checked and repaired annually.

The lobsters are caught by several methods. Fishermen in a boat may shake the shelters with a hook and catch the lobsters with a scoop net as they escape. Divers may also facilitate capture and trap the lobster in nets as they scurry away.

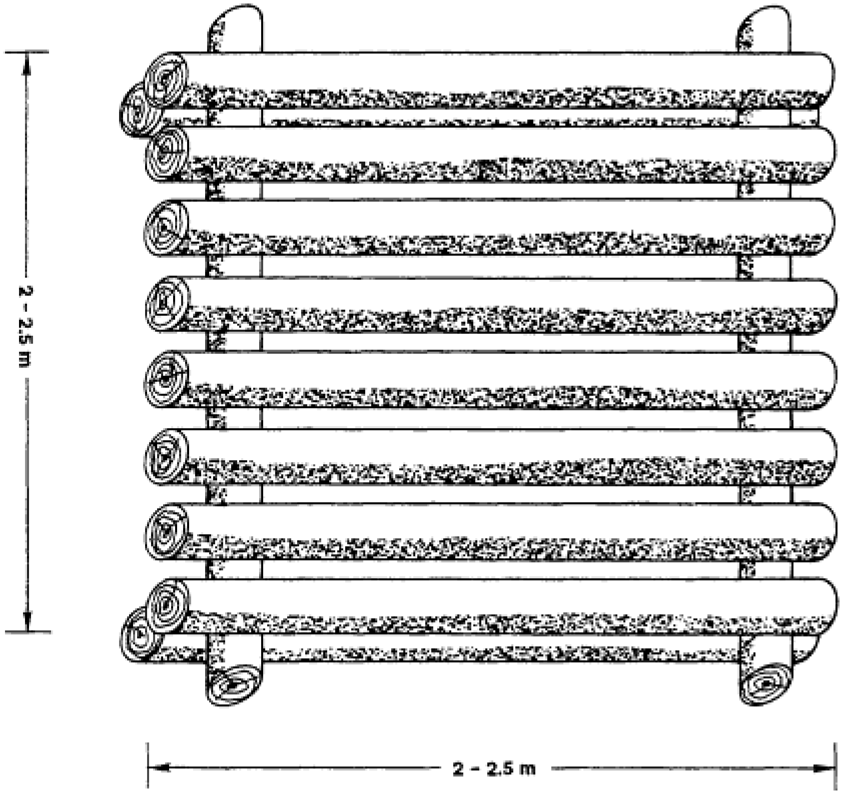


Figure 3.2
A traditional Cuban lobster shelter is used at 4-6 m depths to attract lobsters and facilitate their capture.

In the Gulf of Batabanó on the south coast of Cuba, fishermen from local cooperatives have placed some 120,000 lobster shelters and annually harvest 7,000 tons of lobster from them.

Shelters are increasingly being constructed of ferrocement, since it is illegal to cut mangroves. Moreover, ferrocement has a longer life than wood. The ferrocement shell is mounted on two wooden branches that may sink into the sediment, leaving space for the lobsters under the shelter.

In the Mexican state of Quintana Roo on the Caribbean, fishermen have operated an extensive artificial habitat for spiny lobsters (*Panulirus argus*) since the late 1960s. About 10,000

1.5-m^2 shelters have been installed in a back-reef and bay area. The shelters are constructed on a frame of the trunks of the thatch palm (figure 3.3). Originally, the roof was also made of this palm, but newer styles use a variety of materials including barrel lids, corrugated roofing material, and ferrocement (figure 3.4). The shelters are known by a number of different names including *casitas, sombras* , and *casas Cubanas*, the latter designation in honor of the fishermen who introduced their use. The shelters are assembled on shore and then ferried to areas of shallow water where they are sunk. They are positioned about 20-30 m apart, and are reported to last for 6-8 years.

Rubble and Rocks

The traditional Japanese artificial reef involved simply placing shore or quarry rocks at shallow depths as a way to enhance fishing grounds.

In northern Japan, fishermen have placed rocks to enhance kelp production since the late 1600s. In the 1870s, fishermen from Toneichi, Iwate Prefecture, transported more than 100,000 rocks (40-50 cm in diameter) for the cultivation of seaweed. Currently, rock reefs are used in Japan to enhance seaweed production and to create habitats for abalone, snails, sea urchins, crayfish, and sea cucumbers.

The size and arrangement of the rocks depend on the target species. A single layer is sufficient as a seaweed substrate. Immature sea urchins and abalone prefer crevices, and for these species a layer of rocks 0.4-0.6 m high is ideal. Higher piles of rocks are useful for attracting fish.

Since rocks may be moved or buried by storms, they are often placed in an enclosure called a futon cage because it has the shape of a Japanese floor mattress. Futon cages are now made of synthetic fiber nets. They measure 4 × 1.2 m and are about 0.5 m in height. The rocks used have diameters of 20-50 cm. Because of their weight, futon cages are quite stable on the sea bottom.

The cages are placed in a solid area or in a line with 2 m between cages. Alternatively, they may be arranged to form a 10 × 14 m rectangle. Thousands of futon cages are employed in northern Japan.

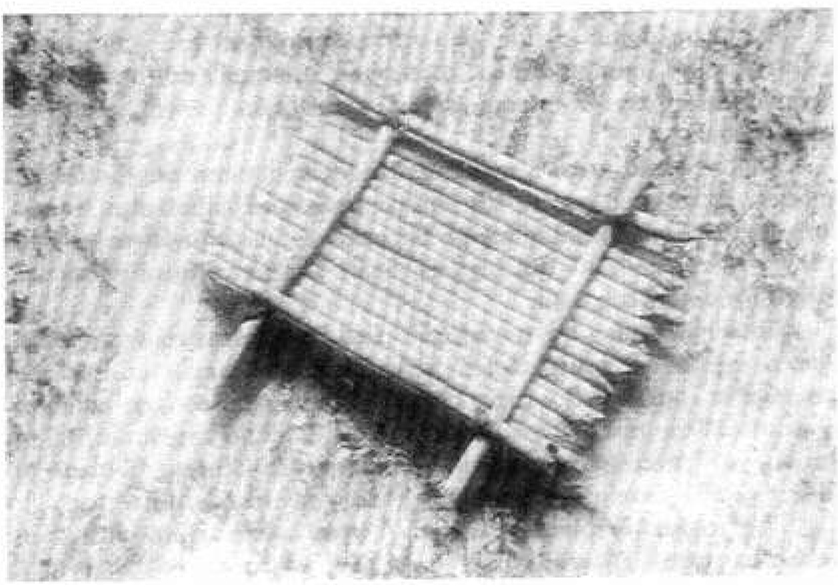


Figure 3.3
Mexican fishermen construct a lobster shelter similar to those used in Cuba. (D. L. Miller, World Wildlife Fund)

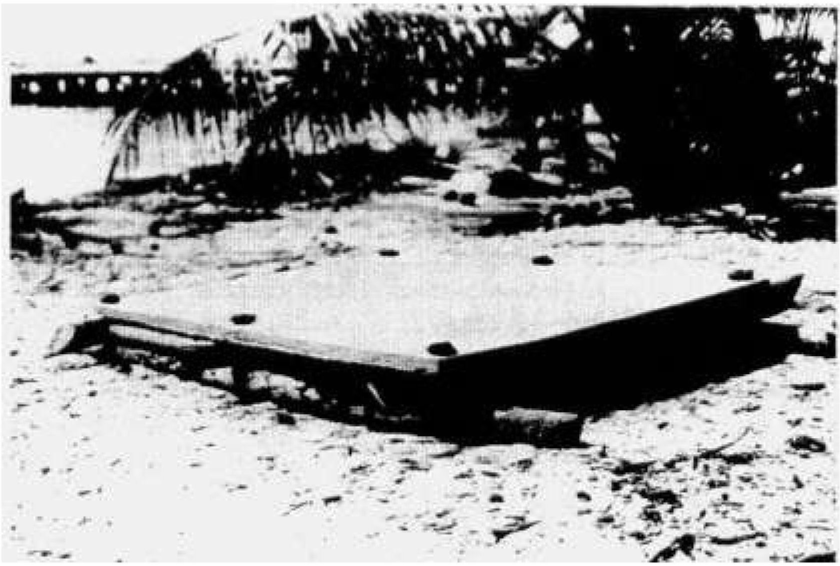


Figure 3.4
Ferrocement slabs can be used to make a more durable lobster shelter. (D. L. Miller, World Wildlife Fund)

Tires

In many developing countries, old tires have a high economic value and, therefore, may not be appropriate for artificial reefs. However, tires do not disintegrate in seawater and are fairly easy to handle.

Scrap tires are somewhat problematic as reef materials because of their low density and tendency to trap air. Regardless of the number of tires that are secured together in a bundle, the structure will move with currents and wave motion unless adequately ballasted.

In Virginia and New York (USA), slit tires have been imbedded in a 10-cm concrete base for use as a reef module. A steel rod or cable is passed through the tires for additional reinforcement. Once placed, these units may subside slightly, but have shown no tendency to move or deteriorate (figure 3.5).

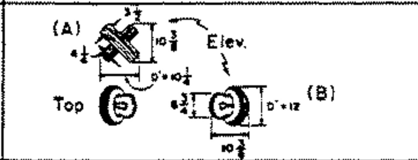
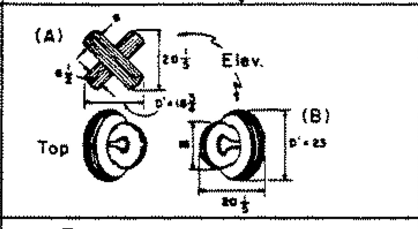
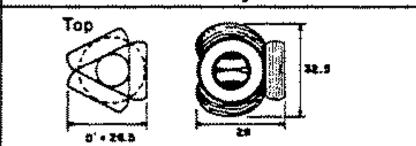
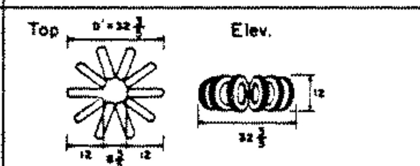
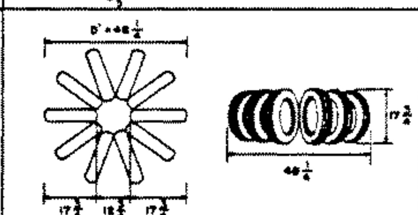
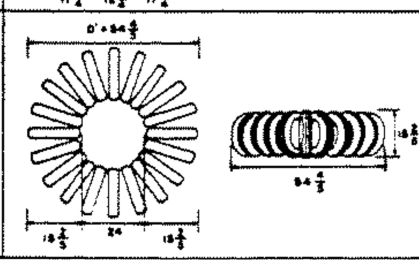
Researchers at Oregon State University (USA) have investigated the underwater stability of various types of complex tire configurations. Among these are rows, triangles, rosettes, and even one tire stuffed into another (figure 3.6). All the tires were ballasted with concrete to increase the submerged weight. This study tested the feasibility of a 500,000-tire reef planned for waters near Winchester Bay, Oregon.

Thailand's Department of Fisheries sponsors numerous artificial reef projects at Rayong in the Gulf of Thailand in order to develop fishing grounds for artisanal fishermen. Automobile tires are among the materials used in these projects. The tires are tied with wire into quadripod modules, each containing 8 tires (figure 3.7). Each artificial reef project employs between 50 and 560 modules of water depths between 4 and 18 m. Another program near the National Institute of Coastal Aquaculture at Songkhla uses structures of 40 tires tied together in 2 rows of 20. The units are placed in water depths of 6-7 m.

An experimental artificial reef constructed of old tires has been placed near Haifa, Israel. The Fisheries Technology Unit of the Israel Ministry of Agriculture sponsored this project. Since the eastern Mediterranean is very unproductive and has a fiat, sandy bottom, it offers little refuge and few spawning sites for fish. The artificial reef succeeded in increasing the fishery yield.

The principal unit had a concrete base that was 3.3 × 3.3 m.

Figure 3.5
Scrap tires can be used to make artificial reefs, but unless firmly ballasted, they will be swept away by waves, currents, or storms. (D. Feigenbaum)

Configuration	Dimensions (inch)	A (ft²)	V (ft³)
2 Tires stuffed (D = 1.0')		(A) .55 (B) .68	1.5 x .34
2 Tires stuffed (D = 1.9')		(A) 1.68 (B) 2.53	1.5 x 2.22
4 Tires triangle (D = 1.9')		.75 x 4.91	.80 x 5.78
10 Tires rosette (D = 1.0')		2.72	10 x 2.29
10 Tires rosette (D = 1.5')		5.95	10 x 7.16
20 Tires rosette (D = 1.3')		5.86	20 x 8.89

Tires were connected to the base by a framework of steel bars (figure 3.8). In an effort to increase the spaces and surfaces of the tires, some of them were placed vertically, some horizontally. The 3-m high structures were constructed on land and lowered into the water with a crane.

Figure 3.7
In Thailand, automobile tires are assembled for an artificial reef. (J. Munro)

Cement and Concrete Structures

Although too costly for most artisanal fisheries cooperatives, concrete artificial reef modules could be used in a national fisheries plan to benefit small-scale fishermen. These materials are durable, of sufficiently high density so as not to be displaced by bottom currents, and can effectively close an area to trawling.

The Japanese are leaders in this technology and have developed hundreds of types of concrete modules to improve fishing grounds. The simplest structures are open concrete cubes with sides measuring 1 m, although larger varieties also exist. A variant has an algae-covered mesh on the cubes top surface. Other structures are cylindrical and box-shaped with many variations in the size of the openings. An igloo-shaped unit has given encouraging results in the Chesapeake Bay in the eastern United States (figure 3.9).

Damaged concrete pipes have been used for artificial reef construction in Hawaii. The pipes varied from less than 0.3 m to as much as 2 m in diameter and from 0.3 to 4 meters in length. Many

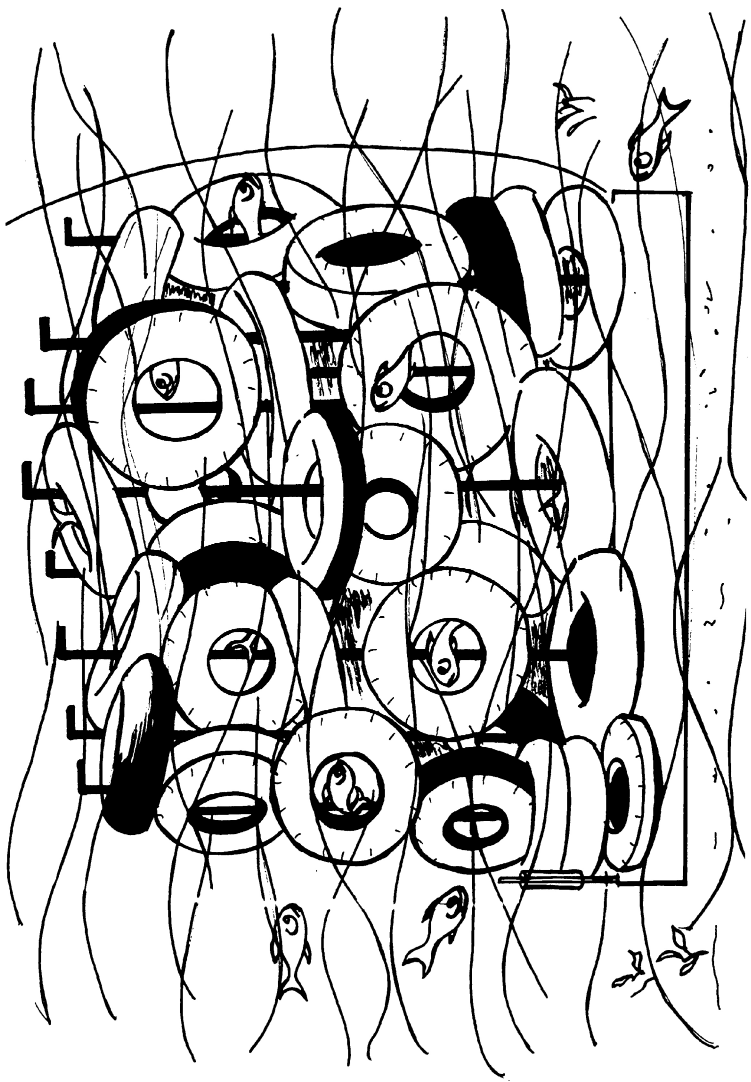


Figure 3.8
In Israel, steel rods fixed in a concrete base serve as a matrix for used tires in an artificial reef.

tons of concrete pipes have been placed on the fiat and sandy bottom in 23 m of water off the western coast of Oahu. Standing fish crop estimates were 5-10 times higher than the pre-reef counts. Juvenile fish grew to maturity on the reef, indicating that productivity can be improved for more sedentary species. Pyramids of 6 pipes, 0.6 m in diameter and 3 m in length, have also been evaluated in Virginia (figure 3.10).

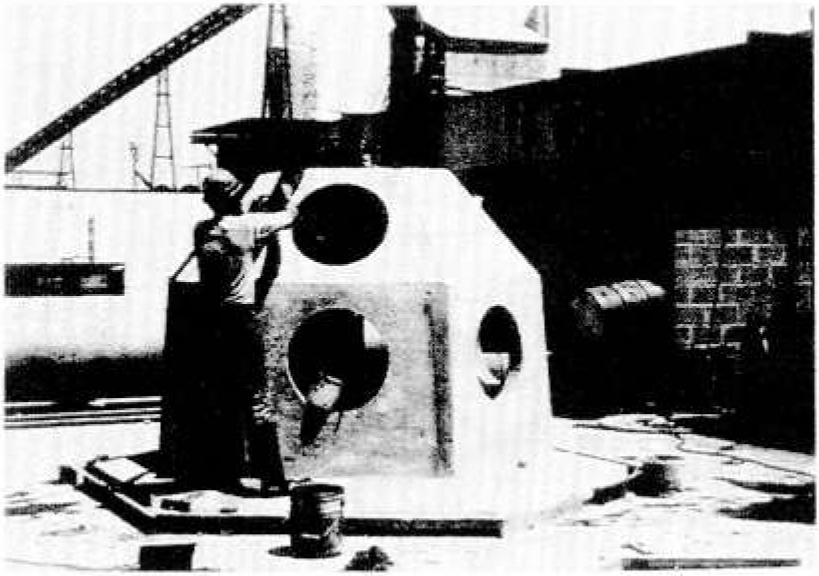


Figure 3.9
An igloo-type structure is fabricated for deployment in the Chesapeake Bay, USA. (D. Feigenbaum)

In Taiwan, concrete blocks have been used on sandy bottoms for over 10 years. Recent efforts have centered on placing concrete modules on the bottom under floating fish cages and longline oyster cultures. The blocks have a volume of 1 m^3 and are placed in 12-15 m of water. The inner space is designed as a shelter for such reef fish as snappers and groupers.

The primary objective of the artificial reef program in the Gulf of Thailand is to enhance fishing grounds for artisanal fishermen. Rayong was the site of the first reef, which was constructed in 1978. Seventy concrete framework cubes measuring 0.5 m on a side and 50 quadripod modules of 8 tires each were dropped in 18 m of water over an area of 1,200 m^2. Additional reefs have been constructed annually since 1978. All were situated on sandy bottoms near fishing villages. Concrete modules have been placed throughout in the 50-km^2 project area. If the area is trawled, the trawl nets will be damaged by the concrete modules. The hypothesis is that the artisanal fishermen's catch using traditional fishing arts will increase in areas where trawlers are excluded. In other areas, trawler exclusion modules are also being combined with groups of artificial reefs.

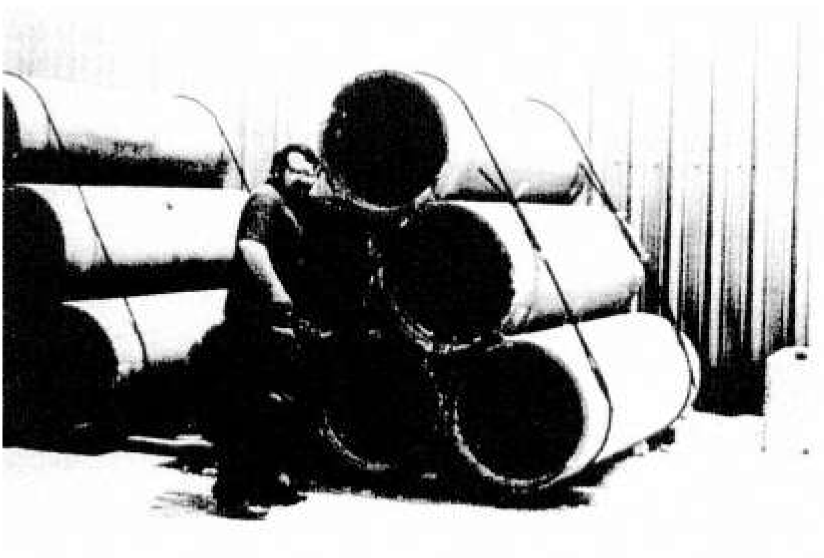


Figure 3.10
Damaged drainage pipes are widely used as artificial reefs. (D. Feigenbaum)

The artificial reef at Songkhla, which was constructed in 1982, covers 2,500 m^2 of sandy bottom. Different types of modules have been used in this project. Twenty 40-tire units were placed at 6-7 m water depth during the first year. One hundred twenty open concrete cubes measuring 0.8 m on a side followed in 1983. Juvenile green sea mussels were attached to the cubes before placement to increase biomass at the site.

Evaluations of the fish catch at the Rayong reef have been inconclusive. A definite change in composition of the catch has been noted, however. Predeployment catches indicated a typical soft-bottom community dominated by croakers and catfish.

Catches at the reefs show a high proportion of valuable groupers and snappers, which normally are not found on muddy bottoms.

An additional artificial reef site is near the Phuket Marine Fisheries Station in the Andaman Sea, Thailand. In that area, 10 reefs have been constructed of tire modules, concrete cubes, and pipes (figure 3.11). The reefs were placed in parallel rows, perpendicular to the trawling path to hinder trawling.

Fiberglass-Reinforced Plastic

Although most fabricated artificial reefs are produced from cement and scrap tires, fiberglass-reinforced plastic (FRP) has also been used. In the United States, ribbons of FRP have been bonded into open-mesh cylindrical shapes (about 1 m in diameter and 5 m in length), and then joined in arrays of 2-10. The raw materials for these units are readily brought to shore areas and are relatively easy to assemble and float to the desired area of use. Cement ballast is used to anchor the units (figure 3.12).

In a Florida trial, all of the components for the FRP reefs were shipped from Japan and assembled at dockside. The units were

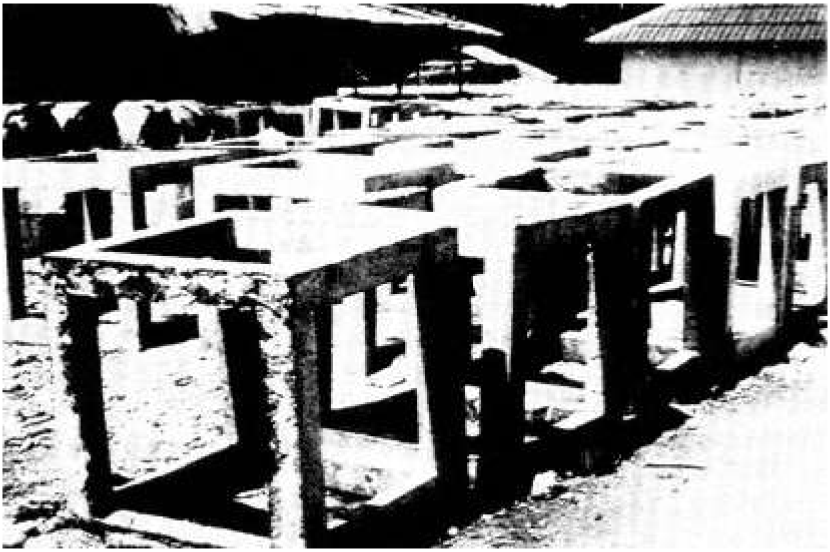


Figure 3.11
Concrete cubes are fabricated for an artificial reef in the Andaman Sea, Thailand. (J. J. Polovina)

ballasted with cast concrete, and reusable airbags were employed to float the units to the placement site. As the airbags were deflated, the reef sank, and the flotation devices were recovered for reuse (figure 3.13). A concrete culvert reef with approximately the same size and volume as the FRP unit was constructed at the same site, and a control area in the same vicinity was identified. Research surveys of these three areas were then conducted every 2-4 months.

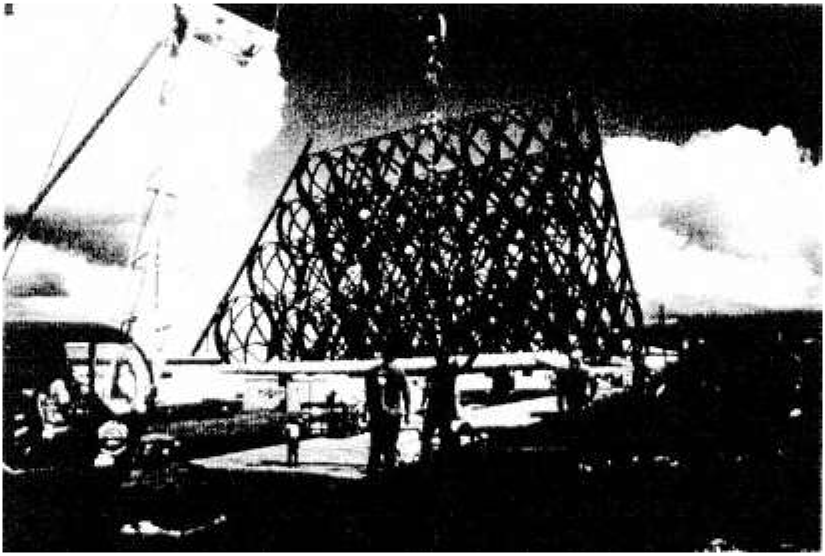


Figure 3.12
A fiberglass-reinforced plastic (FRP) reef is loaded on a barge in Hawaii for deployment at a depth of 120 m to concentrate snappers. (R. Moffitt)

Preliminary analysis of the survey data for the first 18 months indicates that the FRP reefs appear to attract and retain a significantly greater total abundance and diversity of fish, and have much richer epibenthic communities than the culvert reefs. In particular, the FRP reefs have been more effective for larger midwater predators such as the greater amberjack and king mackerel, and seem to have a larger number of the bait fish and juveniles on which these predators feed.

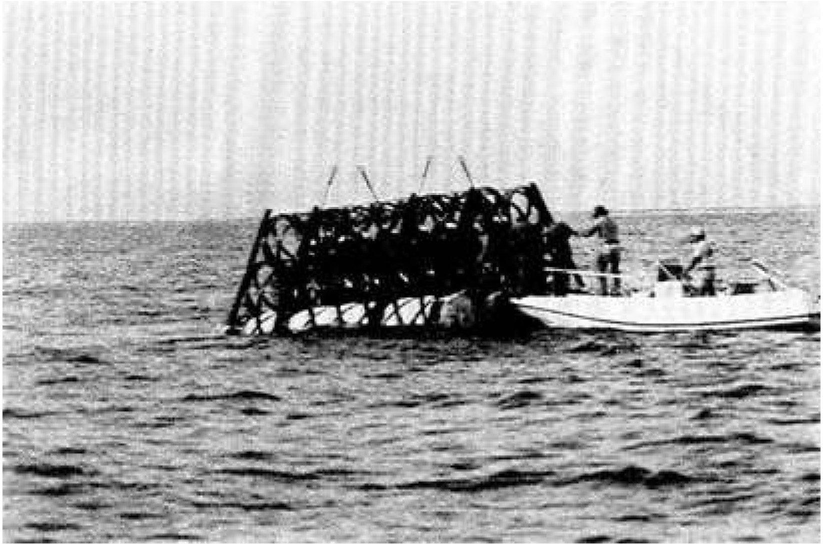


Figure 3.13
An FRP reef module is positioned for placement off the coast of Florida; © 1981, Aquabio, Inc.

Drilling Rigs

When offshore oil and gas drilling rigs become obsolete, they can be used as artificial reefs in some cases. In the United States, Tenneco Oil has dismantled a drilling rig and moved sections of its steel towers to locations to serve as artificial reefs (figure 3.14).

FISH AGGREGATING DEVICES

Pelagic fish, such as tuna, billfish, yellowtail, mackerel, sardines, sharks, and dolphins, are attracted to floating objects from which they seem to obtain some spatial reference.

Surface and midwater attractor reefs or fish aggregating devices capitalize on this behavior. These may be used alone or in combination with benthic artificial reefs. Although recent FAD designs are made of durable materials, less durable traditional structures have been used for centuries.

As a management tool, FADs should be accessible to the target population of fishermen and located in an upwelling zone or along a migratory pathway. A combination of artificial reefs with FADs could enhance several different types of fisheries in the same area. FADs might also be used to shift a fishery closer to market or to a safer location. Landings of migratory pelagic species could be increased by locating FADs in areas where bottom-dwelling fish are overexploited, providing an alternative catch to preserve the livelihood of artisanal fishermen.

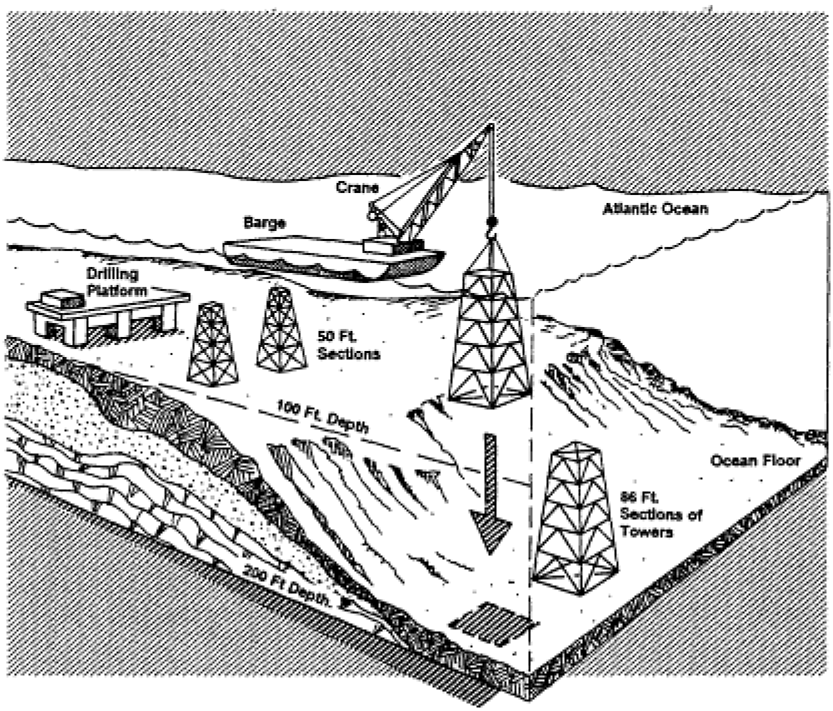


Figure 3.14
When drilling rigs become obsolete as oil producers, they can become fish producers. Tenneco Oil is relocating steel towers from such a rig for use as artificial reefs off the Florida coast. (R. Brownlee, Miami Herald)

Traditional FADs

Japanese fishermen still use rafts made of bamboo bundles (1 m × 8 m) to attract dolphin fish (*Coryphaena hippurus*) and tuna. The fish hiding beneath the rafts are caught by encircling nets.

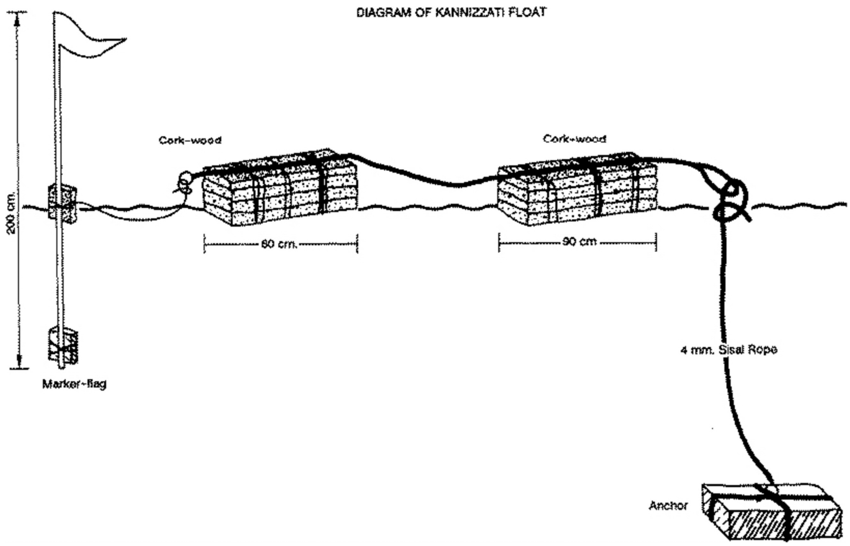
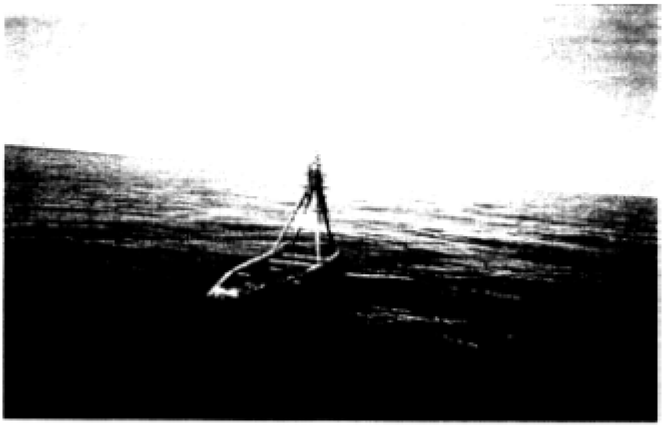


Figure 3.15
Maltese fishermen use these cork floats to attract dolphin fish and pilot fish. Encircling nets or hooks and lines are used for capture.

In the Mediterranean, near Malta, dolphin fish and pilot fish appear from August to December. Both of these species seek shelter under floating objects. Maltese fishermen take advantage of this behavior by anchoring cork floats at intervals of about 1 mile to as much as 80 miles from shore. The floats, a signal flag, and a limestone anchor are linked with sisal rope and are deployed at depths ranging from 150 to 800 m. Fish attracted to these floats are captured by encircling nets, surface longlines, or trolling. This gear is described locally as a *kannizzati* fishery (figure 3.15).

In the Philippines, *payaos* (bamboo rafts) are used to attract tuna (figure 3.16). Fishermen anchor *payaos* with rocks in very deep water. These rafts are approximately 1.5 m wide, tapered at one end, and about 4 m long. Coconut palm fronds are suspended about 20 m below the surface. The *payaos* are fished by purse seiners and have produced catches of up to 200 metric tons per set.

A very similar technique is used in Malaysia. A lure line is supported by a bamboo raft and is anchored in position. The fishing



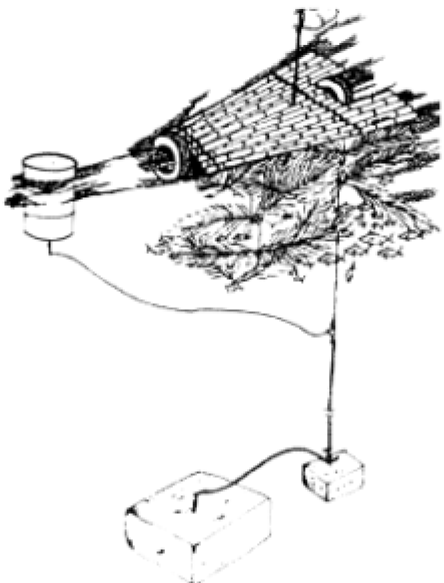


Figure 3.16
The top photo shows bamboo raft (payao) anchored in deep water in the Philippines to attract tuna. (W. Matsumoto) Payaos are about 4 m long and taper from about 0.5 m to 1.5 m wide (bottom). Palm fronds are suspended about 20 m below the raft. (E. O. Murdy, ICLARM Newsletter)

line, called *roempon*, is prepared by attaching palm leaves or bundles of grass along the line (figure 3.17). Dip nets or surrounding nets are used to catch the fish attracted to the device.

In the equatorial western Pacific, floating branches, trunks, and trees attract large quantities of tuna and other pelagic fish. Diverse, vertically stratified marine populations develop around these logs and trees. Directly beneath the floating timber are communities of smaller fish collectively serving as bait for predators below. Organisms growing on the log provide food for the bait, and the log itself serves as shelter. Sharks occupy the next lower niche and feed on the bait. Tuna occur at greater depths with mixed schools of skipjack and small yellowfin appearing above the large yellowfin and bigeye. Bigeye tuna remain at depths of 50 m or more during the day but move toward the log at night. Skipjack and yellow fin tuna are often seen on the surface during the day, downwind of the log. In addition to the fish, a number of turtle species, sea snakes, sea birds, and marine mammals occasionally visit the log communities.

Several characteristics improve the likelihood of log colonization: a minimum size of about 2 m in length by 0.1 m in diameter, the presence of submerged branches or roots, and time enough at sea for barnacles and algae to become established. To be most effective, such floating logs should be no closer than 5 km from each other.

The catch around such logs can be impressive. Purse-seiners have landed 150 t from the sea beneath a 2-m log. A 90-m tree yielded a 1,500-t catch over a 2-week period.

For village fishermen, the use of logs or trees as FADs may be a worthwhile approach. Available funds can be devoted to providing a mooring system for essentially free FADs.

Modern FADs

Recent innovations in FADs improve on the durability of the traditional structures by using plastics and artificial fibers. Used mainly to attract migrating pelagic species, these midwater or surface FADs consist of the main fish attractor, a mooring line, a concrete or sandbag anchor, and a surface or subsurface buoy to suspend the FAD.

One type of midwater FAD is constructed from a metal or plastic frame covered with nylon fabric, plastic film, or canvas

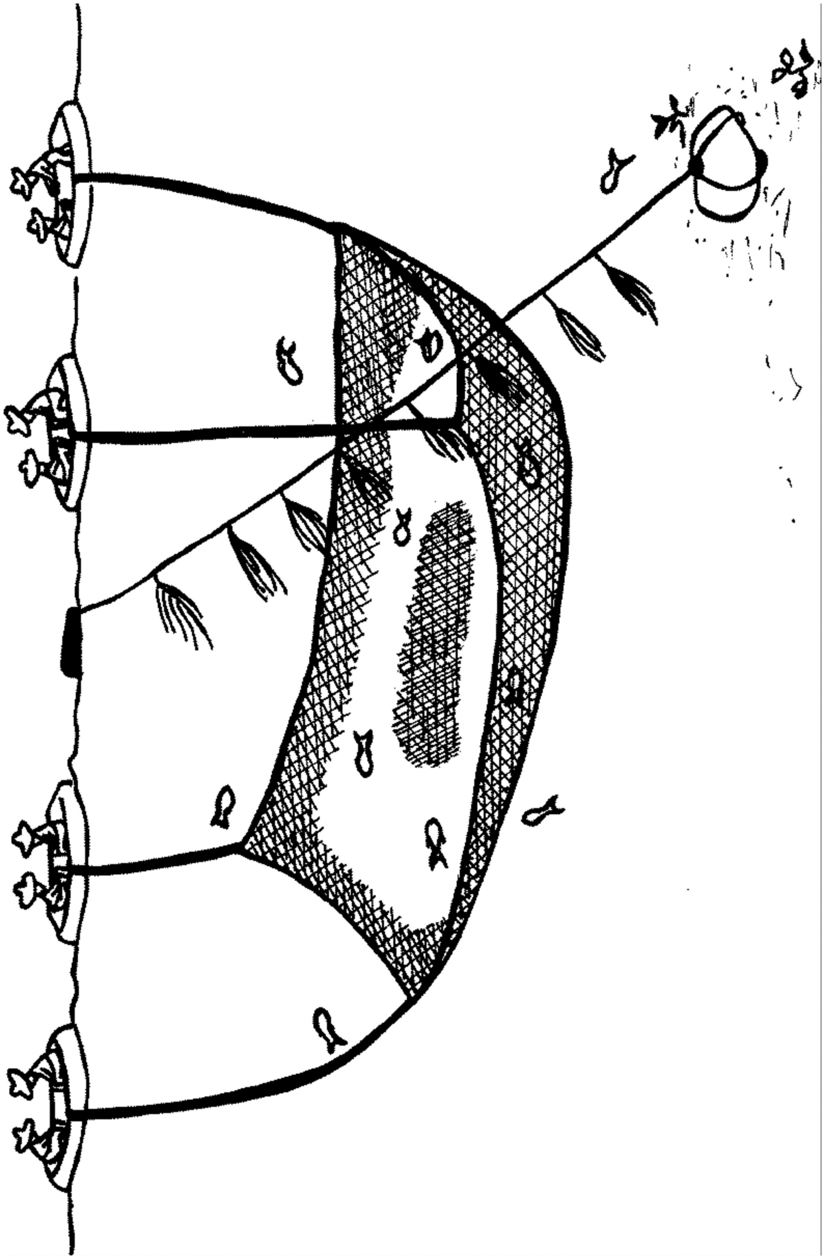


Figure 3.17
In shallower waters in Malaysia, rafts and frond-covered lines called roempons are used to attract fish.

(figure 3.18). McIntosh Marine of Florida has designed a large parasol FAD to use in deep water with strong currents. Four plastic rods radiate from a metal alloy cone, and nylon fabric covers them to form a pyramid. These structures measure 5.2 m high by 8.2 m diagonally at the base. The metal cone is attached to the mooring line at chosen depths in the water column. In strong currents, the pyramid contracts slightly due to the force of the water against it, thus reducing drag. A smaller version of this parasol FAD, the mini-FAD, measures about 1.8 m in height.

Figure 3.18
Midwater FADs made from plastic rods and nylon fabric have been widely used in the Caribbean. (McIntosh Marine)

McIntosh Marine has deployed its mini-FADs throughout the Caribbean to serve different needs. In St. Kitts, Barbados, and Trinidad and Tobago, midwater fish attractors have been placed to improve landings of pelagic fish for artisanal fishermen and fisheries cooperatives. In Barbados, a project is being designed to shift the fishing effort from demersal species in an overfished traditional fishing area to migratory pelagic species farther offshore.

In recent years, more than 300 surface FADs have been deployed in the central and western Pacific and Indian oceans. Much of the development work for these structures occurred at the Southwest Fisheries Center Laboratory in Honolulu, Hawaii.

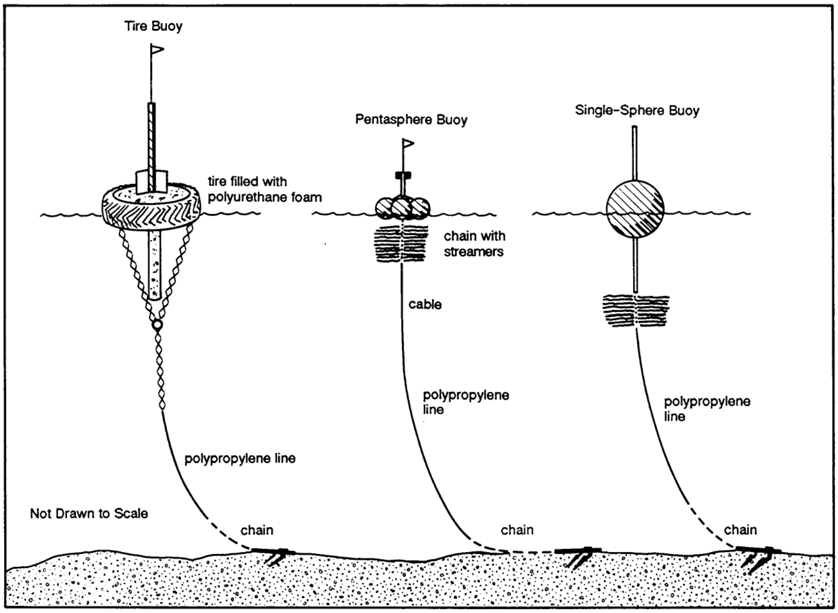


Figure 3.19
In Hawaii, several different designs for FADs have Been tested. The most successful is the single-sphere Buoy.

Most of these FADs consisted of two 208-1 steel oil drums filled with polyurethane foam and held together in an iron frame with about 13 m of polypropylene rope netting draped from the floats. These FADs are anchored to concrete blocks in water depths of 400-2,300 m. They have been successful in recruiting skipjack tuna (*Katsuwanus pelamis*) in quantities sufficient to warrant commercial fishing with pole-and-line vessels.

Other work in Hawaii has involved FADs with several different designs (figure 3.19). Tire-based FADs were made from discarded sugarcane truck tires filled with polyurethane foam. These were unwieldy at sea and were replaced by pentasphere FADs. The pentaspheres, made from surplus steel buoys welded together, generated considerable drag under strong current conditions and broke their mooring lines.

Single-sphere FADs were then constructed and tested. These produced less drag than the previous designs, and currently all new and replacement FADs have this design.

The total catch at 29 FADs over three-and-a-half years was estimated at 4 million pounds. The major species captured were yellowfin tuna, skipjack tuna, marlin, and dolphin fish. These comprised 96 percent of the total reported catch. The principal fishing gears used were pole and line, hand line, and trolling.

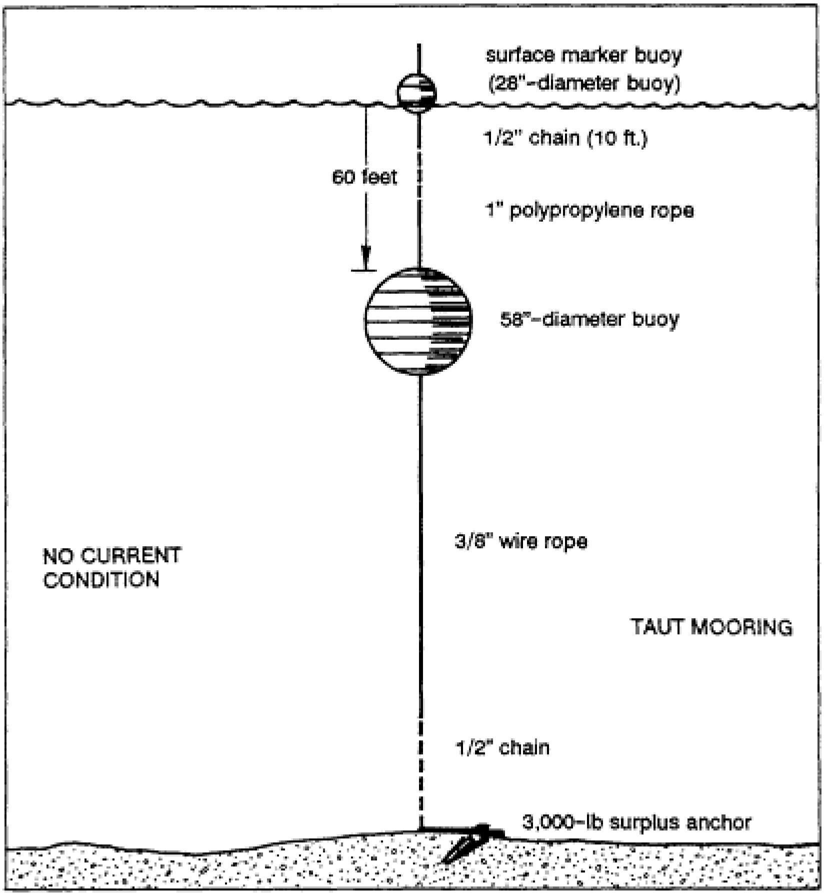


Figure 3.20
A sub-surface FAD is also being tested in Hawaii.

An experimental subsurface FAD (figure 3.20) is also being tested in Hawaii. It consists of a 28-inch diameter marker buoy at the surface attached to a 58-inch diameter buoy at a 10-fathom depth; the buoy is connected to the anchor line. It is believed that this configuration will better tolerate strong surface currents and storm waves.

RESEARCH NEEDS

Although they have been used for centuries, artificial reefs and FADs have not been subject to rigorous scientific analysis. Literature on artificial reefs tends to be descriptive and speculative, not quantitative. Efforts have centered around reef construction and design, but little is known of the basic biology involved or the impact of the reefs on the fish stocks. The relative importance of attraction versus production must be addressed. This will require collection of catch and effort data from a wide variety of artificial reef sites before and after deployment, and must include adequate controls.

Improvements can be made in reef designs. The optimal reef size, configuration, and design should be determined for various environments and purposes. Experiments should be designed to include both controls and replicates. Cost-effectiveness should be determined, especially for developing country applications.

Specialized reefs for fish recruitment, growth, and spawning need to be developed. The use of artificial reefs as stocking sites for juveniles from a land-based hatchery should be explored.

Little is known of the social benefits of artificial reefs and FADs. Conflicts between users must also be explored and reduced.

LIMITATIONS

Although in practice artificial reefs and FADs have enhanced fisheries in certain areas, they are not a panacea for all problems in fisheries. Since the deployment of artificial reefs has generally resulted in substantial aggregations of fish, the use of such devices without careful planning is not recommended. Prior to use, careful thought must be given to possible long- and short-term effects on the general environment in which they are deployed. Increased ease of capture also increases the danger of overexploitation.

User conflicts may result over the commercially valuable catch at the reef site or from a decreased stock in adjacent fishing grounds. Reef construction costs vary widely with location and type of construction material. Caution must be taken to avoid toxic materials that may contaminate the environment. For example, oil and gasoline should be removed from vessels or vehicles before they are deployed as artificial reefs.

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4

Coastal Mariculture

Marine resources in many coastal regions are overexploited. Mariculture, the deliberate production of marine plants and animals, may offer one solution to this problem; principles of agriculture can be applied to improve yields of selected marine species.

Marine plant and animal production is controlled by a number of basic chemical and physical constraints. Assuming that the organisms under consideration for coastal mariculture are indigenous, physical factors such as salinity and temperature should not be limiting at normal animal densities. Environmental factors such as wave action and solar energy are also important in planning mariculture activities. Nutrients are essential for all plant or animal production. Some coastal areas are rich in available nutrients; in other regions, strong current flows and wave action can provide large quantities of nutrients for plant production. A critical initial consideration is the cost and availability of nutrients for the specific organisms to be cultured. In some cases, controlled enrichment may be necessary.

If the animal to be cultured is a grazer of phytoplankton or benthic algae, the conditions for sufficient production of these feed sources must be present. Animals feeding higher in the food chain have similar constraints, but the requirements are more complex.

Many underutilized coastal areas have potential as sea farming sites. These activities would not compete with terrestrial farming for space, and many culture techniques are technically unsophisticated and could be implemented by small family units without large investments. This chapter will cover the mariculture potential of species in three major categories: algae, finfish, and crustacea and molluscs.

ALGAE

As with land plants, algae can be cultivated as animal feed, as human food, or as a source of industrial products. In addition, algae may be part of low-cost systems to recycle domestic or agricultural wastes or wastewaters.

Algal Turf Mariculture

Recent research by the Smithsonian Institution's Marine Systems Laboratory (MSL) has shown that mariculture of fine algal turfs, commonly found on highly productive coral reefs and similar hard bottom communities, is biologically feasible. The tropical open ocean is known to be nutrient poor, and its fisheries development potential has long been considered rather limited. Coral reef ecosystems, however, maintain production rates of between 10 and 20 g dry material per m^2 per day (10-100 times the productivity of tropical nutrient poor water). They derive nutrients from tropical currents, upwelling of deeper ocean water, and the constant wave action of trade wind seas.

Under proper environmental conditions simulating reef processes, algal turfs may be grown on screens. This production can serve as feed for marine animal grazers that, in turn, could be consumed by humans. Several species: *Mithrax spinosissimus* (Caribbean king crab), *Cittarium pica* (whelk), and *Scarus* (parrotfish) have served as target herbivores for MSL algal turf research. The life cycles of these animals have proved satisfactory for controlled spawning and grow-out. Pilot projects for algal turf mariculture are operating in the Turks and Caicos islands, the Dominican Republic, and Antigua. In all these projects, algal turf, a mixture of red, blue-green, and green algae, is grown on plastic screens and used as feed for the target animals (figure 4.1).

Figure 4.1
Algal turf, a mixture of red, blue-green, and green algae, is grown on screen suspended in nearshore waters. When covered with algae, the screens are used to feed caged crab (shown), whelk, and parrotfish in Caribbean pilot projects. (D. Suman)

Sea Farming

Many large marine algae, or seaweeds, are nutritious or provide special flavors and are routinely consumed by Asian peoples. Throughout the world, seaweed extracts are used in a variety of products including foods, biomedical products, cosmetics, and textiles. Agar, a colloidal extract of the red algae *Gelidium* and *Gracilaria*, is used as a gelling, stabilizing, and emulsifying agent in ice cream, jelly, candy, and beer. Agar finds its greatest value as the base for microbiological culture media, critical diagnostic tools used in hospitals and research institutes. Other colloids, carrageenans, and algins extracted from a number of red and brown algae, also have wide application in foods, cosmetics, and pharmaceuticals as thickeners, stabilizers, and suspension agents. Calcium alginate fibers derived from *Laminaria hyperborea* have been used to produce wound dressings that are highly absorbent and hemostatic. Epidemiological studies have indicated lower incidences of some forms of cancer in areas where *Laminaria* or *Porphyra* are a regular part of the human diet. Dietary *Porphyra* is also reported to reduce cholesterol levels in blood. Some marine algae have been evaluated as biomass energy sources through their conversion to alcohol or methane.

Gelidium and *Gracilaria*, the traditional sources for agar, are harvested worldwide from natural populations. This type of exploitation results in a "boom or bust" industry that might be stabilized by mariculture technology. Considerable research has led to pilot seaweed mariculture in areas of California, Florida, Hawaii, the Caribbean, and China with the proper physical climates for these species. Pilot projects often evaluate enclosures of varying levels of complexity.

Giant kelp (such as *Macrocystis* and *Nereocystis*) are also harvested from natural populations off the Pacific coast of North America. Ocean-going harvesters have been developed, and the industry shows a high degree of management including pest control, replanting, and harvesting restrictions.

Mariculture of red algae as a source of the colloid carrageenan is highly developed. Vegetative propagation of *Eucheuma* on nets in the Philippines occurs on reefy fiats with good water circulation. Monofilament longlines are stocked with fist-sized fragments of highly productive seaweed strains. The cultivated plants are harvested at about 3-month intervals. These family farms are maintained using basic agricultural principles, including weeding, predator control, and selection for vigorous strains. Production is 10-15 dry metric tons per hectare per year.

On the South Tarawa lagoon in Kiribati, family-scale production of *Eucheuma* is just beginning. Each family has about a quarter-hectare sea garden. Young growth of *Eucheuma* is tied to lines drawn between mangrove stakes. Trials have shown that a 200 g plant will grow to 2 kg in 8-12 weeks.

Other commercial sources of carrageenan, *Chondrus* and *Iridaea*, are harvested from natural populations in cool temperate waters. Net farming of *Iridaea* in the state of Washington has also been practical.

Mariculture of the edible brown algae *Laminaria* (kombu) and *Undaria* (wakamei) is highly developed in cool to warm temperate waters in China and Japan. In China, billions of *Laminaria* sporelings are produced in large glass houses supplied with seawater. Longlines anchored to the bottom and floated below the surface at proper light levels are transplanted with young plants of selected *Laminaria* strains. Adult plants can grow to 3-6 m in length and yield about 5 wet tons per longline. Other techniques for *Laminaria* cultivation include the application of fertilizer in the sea, breeding of new strains, and disease control of sporeling as well as adult plants. Commercial cultivation of *Laminaria is* being practiced on the entire China coast from Lianoning Province in the north to Fujia Province in the south (figure 4.2). About 275,000 dry tons of Laminaria were produced from 18,000 hectares of marine farms in 1974.

When *Laminaria* is cultivated where herring spawn, the herring lay their eggs on strands of the seaweed. This combination (*kazunoku kombu*) is harvested and sold as a delicacy in Japan (figure 4.3).

Porphyra, or nori, is the most popular edible seaweed in Japan, the country that dominates the world's production of this crop. In China, *Porphyra* cultivation has recently become a large mariculture industry. The traditional farming method involved planting bundles of leafless brush or bamboo in shallow water. The floating spores of *Porphyra* attach to the brush and develop into edible fronds. Modern farming involves growth of spores in indoor tanks with shells of molluscs as substrate and transfer of young plants to synthetic fiber nets for cultivation in intertidal zones (figure 4.4). Crop maintenance includes fertilizing, pest control, and weeding. New developments include floating cultivation in the subtidal zone or shallow sea areas and strain selection and breeding programs.

Algal mariculture has a high potential for development in coastal nations. Initial considerations for such development include evaluation of native and exotic species potentials for different products and cost assessment for the development and implementation of the related industries.

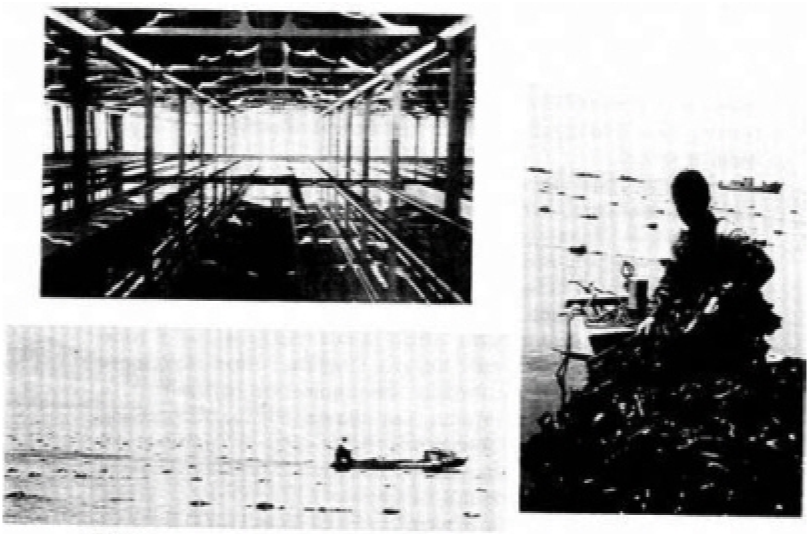

Figure 4.2
In China, mariculture of the seaweed *Laminaria* begins in glass houses. The sporelings produced are transplanted to lines floating just under the surface in bays and estuaries. The plants are sprayed with fertilizer during growth and harvested when mature. (X. G. Fei)

FINFISH

Cage or pen culture is the most promising method for culturing marine fish in corral environments. Freshwater fish were cultured in cages only several decades ago by the Japanese; perfection of this technique has increased yields of yellowtail (*Seriola quineradiata*) to more than 280 metric tons per hectare of cage area. Marine fish aquaculture will inevitably become more popular in the future and might be practiced on a small scale by coastal residents.

Floating fish cages make harvesting much simpler and protect fish from predators. Since the fish have a limited space in which to swim, they burn fewer calories, making food conversion more

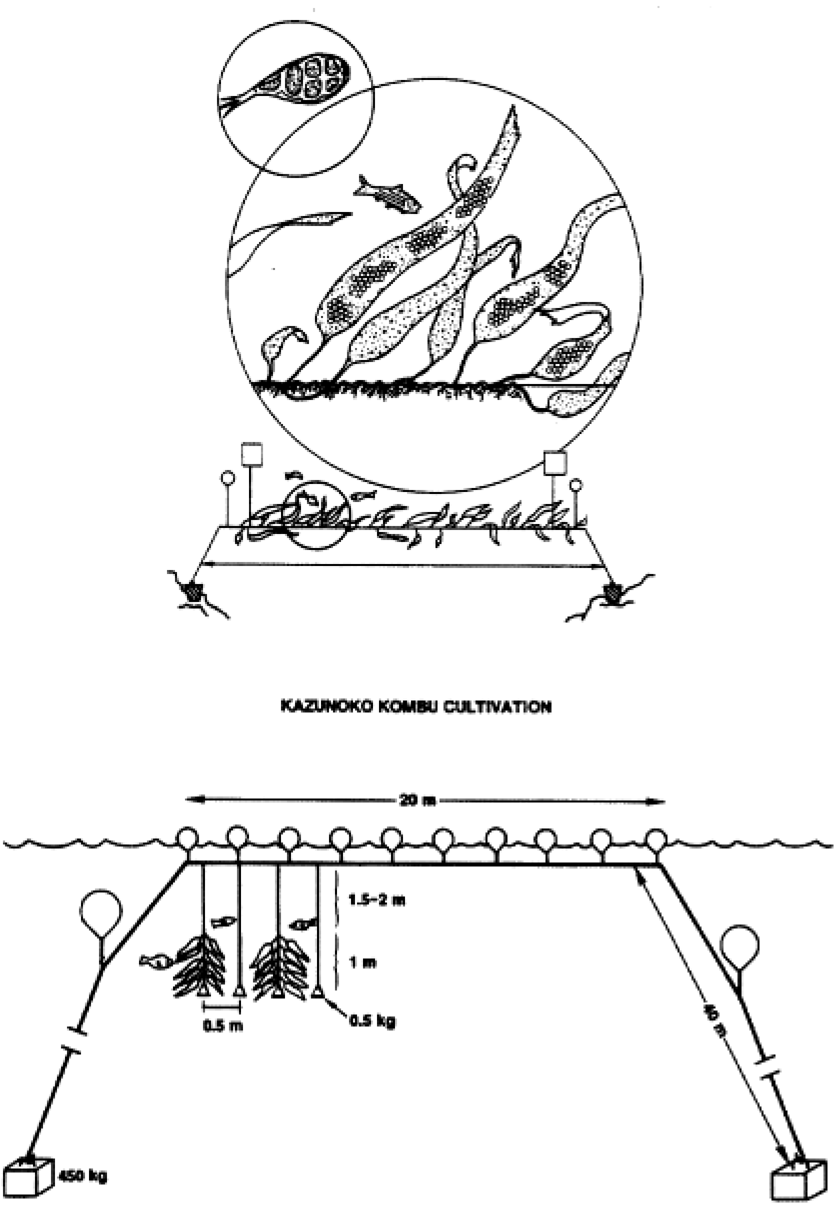

Figure 4.3
When Laminaria is grown where herring spawn, the herring lay their eggs on the fronds. This combination of seaweed and fish eggs, kazunoko kombu, is consumed as a delicacy in Japan.

efficient. Cages can also be moved from place to place and clean, oxygenated water is not usually a limiting factor.

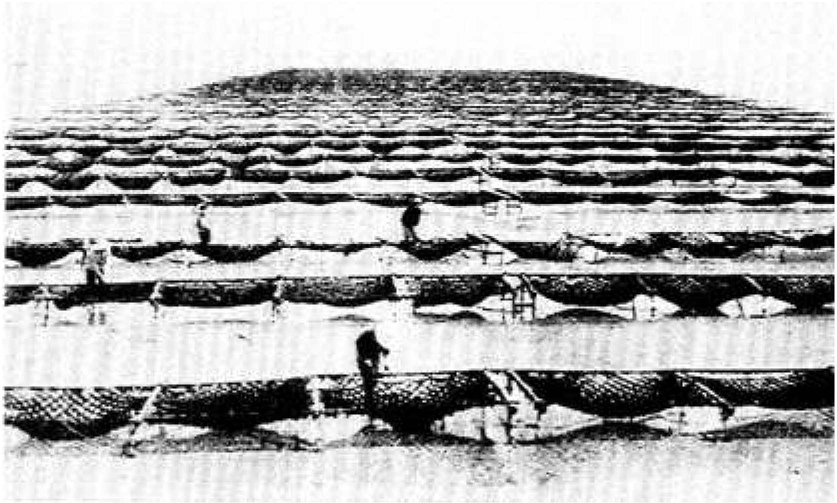

Figure 4.4
In China, spores of the edible seaweed Porphyra are grown on mollusc shells in indoor tanks. The young plants are then transferred to nets in an intertidal zone for grow-out. (X. G. Fei)

Cage cultivation does have drawbacks. The walls of the cages become fouled or covered with algae and must be replaced and cleaned regularly. The high density can lead to disease and parasite problems. Culture is labor-intensive and requires meticulous care. Many fish are extremely sensitive to high levels of pollutants.

Yellowtail

The fast-swimming, pelagic yellowtail (*Seriola quineradiata*) is the marine fish most commonly cultured in Japan. The fry are captured from the sea and stocked in floating nylon net cages, which are between 2 and 50 m^2 in area and from I to 3 m deep. The cages are set out in parallel rows and a platform may be built so that they can be readily attended. After 4 to 6 weeks of feeding and growth, the fry are stocked in grow-out cages. These larger cages, from 35 to 100 m^2 in area and 3 to 6 m deep, may be constructed from nylon or metal. They must be carefully located in protected, accessible areas with good water quality and circulation and appropriate temperature and salinity. Yellowtail are fed fish scraps and less desirable species, so these must be available. The yellowtail are harvested after a 6-month grow-out period.

Dolphin Fish (Mahi mahi)

Recent work on dolphin fish (*Coryphaena*) in the University of Hawaii's Sea Grant Program has shown them to be extremely fast growers and suitable for cage culture. This species is circumtropical and would be ideal for culture in coral atoll lagoons. More work is needed on hatchery and grow-out techniques, however.

Groupers, Snappers, and Sea Bass

Pilot cage culture projects for groupers and snappers have been implemented in Malaysia and the French West Indies. Floating net cages are being tested to fatten undersized fish of fast-growing marine species, such as mangrove snappers (*Lutjanus spp.*) and estuarine groupers (*Epinephelus spp.*). These species are found naturally, are readily accessible, and have a high market value. Juvenile fish weighing 150 g or more are stocked in the cages.

In Malaysia, bamboo rafts (12 × 12 m) are built and floated on discarded oil drums. Four 5-m^3 knotless nylon-net cages are suspended from each bamboo raft. The net is removed from the water and cleaned when its openings are about half blocked by fouling organisms. The rafts are anchored with oil drums filled with concrete, sand, and stone. In the French West Indies, 10 × 3 m cylindrical floating nets are used. In Micronesia, rabbitfish (*Sigamus spp.*), herbivores, are used in floating net cages to consume the fouling organisms and reduce the maintenance of nets.

Milkfish (Chanos chanos)

Milkfish have been reared in brackish waters for centuries. Growth in ponds and pens is very rapid, if adequate algal foods are provided. A recent breakthrough in spawning adults in captivity was achieved at the Oceanic Institute in Hawaii. This should lead to increased availability of juveniles for greater production of this species in Pacific basin countries. The herbivorous nature of this fish would allow the use of low-protein pellet feeds or algae grown either in the culture area or on an appropriate substrate elsewhere. It is a good candidate for polyculture because of its nonpredatory and herbivorous nature.

Mullet

The culture of mullet from the hatchery to pens is still in the pilot stage. Mullet hatchery production is relatively routine, but economic production of this species has yet to be demonstrated in cages, pens, or ponds. However, the desirability and availability of this species makes it a good candidate for culture in certain areas of the world. In Israel, Taiwan, Indonesia, and the Philippines, mullet are incidental crops in milk fish and shrimp-pond culture.

Tilapia

Tilapia have a long history of culture in freshwater systems and have also been commercially reared in coastal waters. The development of salt-tolerant strains, coupled with the limited availability of fresh water in many areas, may encourage coastal production of tilapia in cages. At low stocking densities, tilapia have growth rates of about one g per day. However, in commercial operations with high density and pelleted feed, growth rates of 22-33 g per day have been reported. There are major technical problems with hatchery production or grow-out with this species. Several new strains have been developed, including a red-colored strain, which make the fish more marketable. Tilapia are also being grown in combination with shrimp and various fish species throughout the world.

Rabbitfish

Rabbit fish are a popular herbivorous fish of the tropical Pacific. Hatchery operations have produced marketable sizes on a pilot scale, but commercial culture has not yet been successful. Recent development of the algal turf production technology by the Smithsonian Institution's Marine Systems Laboratory could provide a means for producing low-cost food, which would allow the culture of this species in nutrient-poor tropical waters. Rabbitfish can be used in certain cage culture operations to control fouling of nets and screens; in innovative applications, oyster culture strings were cleared by being placed in cages containing rabbitfish.

Salmon

Pen culture of salmonids is well established in Norway, Scotland, and other northern climates, and several projects are underway for areas of North and South America. Commercial feeds are available, and cage and pen designs have been successful. There are no problems with hatchery rearing before transfer to cages in the marine environment. Specially formulated pelleted foods are provided until market size is reached. New work on manipulating the gene complement of salmon may yield faster growing or sterile fish for certain aquaculture applications.

Ocean ranching, where salmon are produced in the hatchery and then released to the environment, has been successful in Japan and North America and is Being tested in Chile. In Chile, only 1 percent of the first generation returned for capture. Their goal is for 5-10 percent of the annual batch to come back to the release point. Salmon return in 2-4 years after release and are then captured. Technologies have been developed in which salmon literally swim directly into the processing plant.

CRUSTACEANS AND MOLLUSCS

Invertebrates now being cultured include crustaceans and molluscs. The culture method of molluscs depends primarily on the organisms' mode of feeding. Bivalves (oysters, mussels, clams, and scallops) are filter feeders. These animals require a substrate that allows them access to large quantities of water for filter feeding. In the culture of oysters, mussels, and scallops, the substrates are typically ropes, stakes, and mud. Off-bottom rope and stake culture is generally more efficient than bottom culture. In recent years, clam production has been improved by tilling and cultivation of natural mud substrates to improve pH and texture.

Gastropods are snails that feed mostly on bottom-dwelling or benthic algae. In this case, an effective growing surface for the algae as well as a protective cage for the snails are the primary requirements for culture.

Oysters

Oyster farming is one of the oldest forms of mariculture. Transfer of excess young oysters from reproduction areas to grow-out areas has been practiced for centuries. New off-bottom culture techniques produce far higher yields than do natural bottom areas. Environmental degradation of estuarine ecosystems, where oysters reproduce and grow, endangers oyster cultivation in many areas. Even if the oyster grounds are not destroyed, pollutants, which the oysters concentrate in their tissues, can make them unfit for consumption.

Oyster species extend over a broad geographic range, both in tropic and temperate zones, and require areas of reduced salinity. They fall into two groups: flat (*Ostrea*) and cup-shaped (*Crassostrea*). These sedentary molluscs spawn whenever the water temperature remains above a species' specific minimum. Tropical species may spawn year-round, whereas temperate species have limited spawning periods. Depending on species environment and availability of food, they take from 6 months to 5 years to reach marketable size. Bottom cultivation of oysters is used in many areas because of its ease, but it has the disadvantages of low productivity and lack of protection from predators. Farmers prepare the bottom for cultivation by spreading dead oyster shells or gravel over the bottom or by stirring shell-covered bottoms; this provides clean surfaces to which the spat can attach. These preparations occur as close to spawning time as possible. Production can be moderately increased by cultivating the oysters, or by breaking up clusters, removing fouling organisms, and returning the individuals to the substrate. The oyster area can also be fenced off to protect it against predators.

In the Philippines and Thailand, bottom cultivation is called the broadcast (*sabog*) system. Where the bottom is firm, oyster shells or stones are scattered to provide surfaces for oyster larvae attachment. The oysters are simply left on the collectors until harvesting.

Off-bottom cultivation offers the potential for higher productivity and protection against such predators as starfish and oyster drills. In many areas, oysters are grown on sticks in the intertidal or uppermost subtidal zone. Philippine oyster farmers impale tin cans and oyster shells with bamboo stakes (*tulos*) to collect the spat, and then drive the stakes into estuarine sediments and tidal mud flats. The dean stakes, which are 5-10 cm in diameter, are placed just before the oyster larvae are expected to attach. Some farmers increase the surface area available for attachment by adding horizontal bars of bamboo. Harvesting simply involves lifting the stake out of the water and removing the attached oysters. The soft bottom of southeast Manila Bay is literally a forest of bamboo poles used in this type of culture.

Longline cultivation is also productive and economical. Ropes, wires, or branches are hung from a horizontal wire, suspended by buoys or posts; the spat attach themselves to these underwater surfaces. When the oysters are ready for harvesting, the lines or branches are lifted from the water. In the Philippines, the hanging method (*bin*) uses old oyster shells or coconut husks as collectors.

In Japan and the Philippines, longline methods have been responsible for recent increases in natural oyster production. Longlines, 45-75 m long, consist of a pair of ropes strung between pairs of floats, arranged in a row. The floats may be metal, wood, or styrofoam, and are spaced at intervals from 3 to 7.5 m. Three oyster lines, usually 7.5-10 m long, are suspended from each float and are never permitted to touch the bottom. The two end floats are anchored. These longlines allow oysters to be grown in deep water, exposed to the conditions of the open ocean. This system is not easily damaged by waves, winds, or currents.

The mangrove oyster, associated with mangrove roots, has traditionally been collected in Cuba. The introduction of a variant of longline cultivation, in estuaries where oyster spawning occurs, has resulted in a large increase in oyster production. Typically, mangrove or concrete stakes are driven into the mud, at 3-m intervals, to form two parallel rows about 3 m apart and 30 m long. Wooden crossbeams are then attached to the top of each stake above the high-tide levels. Mangrove poles are placed to extend from crossbar to crossbar, forming two parallel lines that extend the length of the structure. Mangrove branches are cut and hung from the poles into the water, serving as a surface for oyster spat attachment. About 150 branches or collectors may be hung from each unit.

An artificial collector has recently been introduced to replace the mangrove branches. The innovation, which simulates a mangrove branch, is made of aluminum wire and has 24 branches. Before it is hung, the artificial collector is given a cement bath, creating an improved surface for spat attachment.

Cuba's largest oyster farm (at Jujuru, Holguín) has a total of 105,000 mangrove branch collectors, each producing about 6 kg of oyster meat annually.

One of the world's largest mariculture activities, pearl culture, is no longer the sole province of Japan. The culture of pearl oysters is being developed in China and French Polynesia.

Mussels

Mussels are widely distributed throughout the world. They are cultured in Western Europe, North America, and Southeast Asia. About 90 percent of the green mussels consumed in the Philippines are cultured. Mussels are easily harvested and their culture is very productive.

The common mussel, *Mytilus edulis*, is cultured in Western Europe and North America, while the most important species in Southeast Asia is the green mussel, *Perna viridis*. Mussels spawn with rising temperatures in spring and summer. Spawning can also be induced by reducing salinity. The free-swimming larval stage lasts for 10-15 days before the larvae settle onto fibrous substances, stones, or shellfish. They are found in estuaries but seem to prefer intertidal zones. Bottom, stake, and line culture are all successfully employed.

Bottom culture of mussels is practiced primarily in Holland, the United States, and Thailand. Fishermen seed designated culture areas with young mussels collected from public grounds. During the grow-out stage, the mussels may be thinned and transferred to deeper grounds.

The stake method is common in France and the Philippines. In Brittany, the seed is collected on long woven ropes suspended in intertidal regions near natural beds. These ropes are then wrapped around 4-m poles embedded into estuarine sediments. The bottoms of the poles are sheathed in plastic to exclude predators. In the Philippines, bamboo poles are driven into the soft mud in water 2-4 m deep shortly before the mussel-setting periods. The stakes are often set in a circle, slanted toward the center, with the top ends fastened or tied by horizontal crossbars. Mussels are usually harvested after 6-10 months of growth.

Productivity is also high in raft-line culture, a method perfected in Spain and also practiced in the Philippines, Western Samoa, and North America. In this method, mussel grow-out lines of nylon, polypropylene, or of local grass are suspended from rafts or lines of floats. These lines should not touch the bottom, since this allows access to crab predators. Anchored rafts are built of wooden timbers or bamboo supported by cubical floats made of wood, fiberglass, or discarded oil drums, and a cross-lattice of sticks is constructed on the platform of the raft. In the longline approach, floats can be drums or large fishing buoys. Hundreds of ropes may be suspended from each raft. A rope-web culture method developed in Sapian Bay, Panay, the Philippines, increased annual production to 300 tons per hectare, over five times the production of stake methods. Culture trials of green mussels attached to ropes suspended from bamboo rafts, have been performed at Asau Bay in Western Samoa. Production has ranged from 7 to 15 kg of mussels per m of rope (figures 4.5 and 4.6).

Clams

Clam fisheries are important sources of seafood throughout the world. Natural populations may be found in both estuarine areas and in more oceanic conditions. Stocks in deeper areas are often exploited by larger vessels. Clam mariculture uses bottom and off-bottom culture methods, similar to oyster and mussel culture. In bottom culture, wild and hatchery-produced seed is planted in managed plots. Bottom culture is generally unsophisticated and is only moderately productive.

Off-bottom culture utilizes trays or cages that contain soil. Hatchery-produced seed of *Mercenaria* may be planted in raised, low-profile rectangular cages. These are arranged in rows in subtidal areas in depths between 2 and 3 m. The containers, measuring 1 × 2 × 0.15 m, have plastic screening on the top and bottom, allowing for water and nutrient circulation. The sides are constructed of treated wood. Seed clams are placed into the 8-10 cm of sediment contained in each cage. Periodic thinning of stock and the removal of fouling organisms add to the labor-intensive aspect of this culture method.

Giant Clams

Giant clams are excellent candidates for broader use in shallow-water ocean farms. They are fast growing and, as adults,

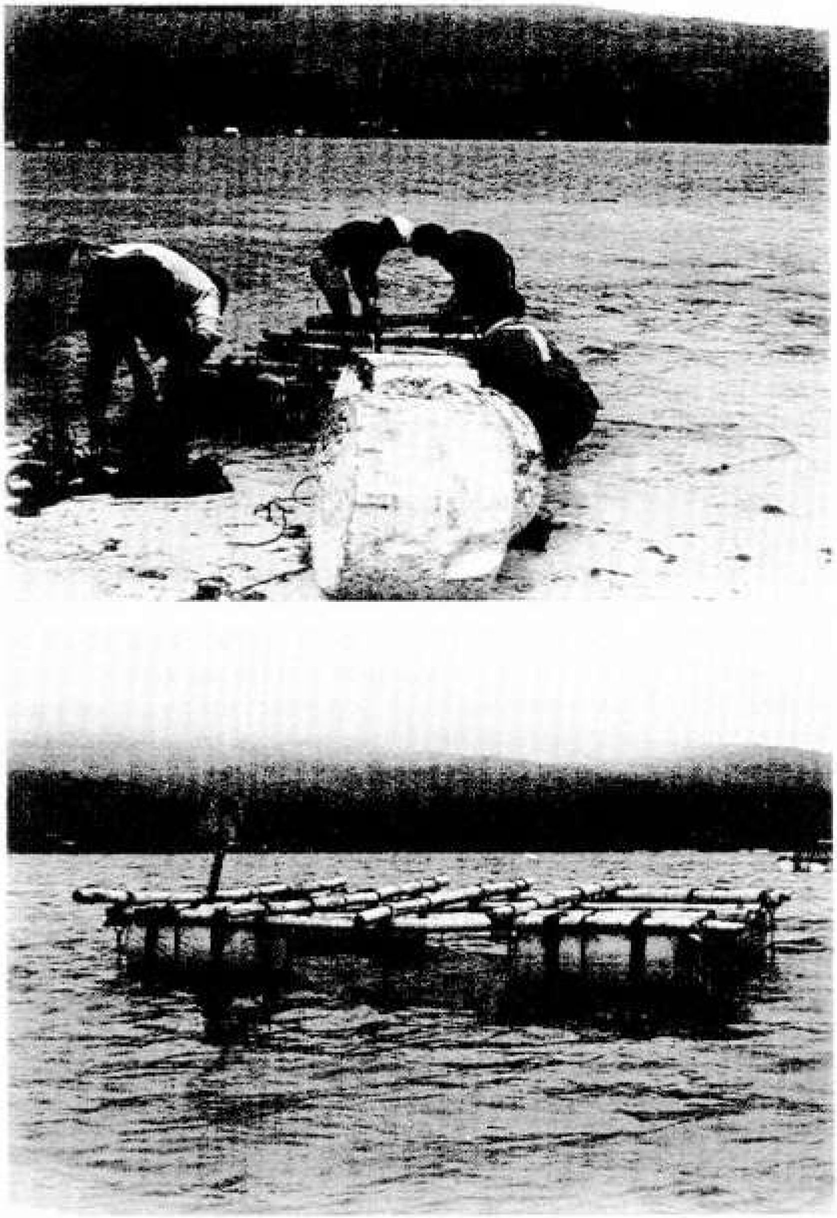

Figure 4.5
Green mussels have been successfully grown at Asau Bay in Western Samoa. Rafts, constructed from bamboo and plastic floats, support the ropes on which the mussels grow. (L. Bell)

sedentary, predator resistant, ecologically innocuous, and commercially valuable.

At the Micronesia Mariculture Demonstration Center in the Republic of Palau, methods for the mass culture of giant clams have been developed. Through careful observation of spawning behavior, larvae were captured and reared in tanks and raceways. Once young clams reached shell lengths of 5-10 mm, mortality rates dropped dramatically, and clams larger than 30-40 mm had a high survival rate in the laboratory. In nature, 10-20 mm clams suffered total mortality from predation within a few days of unprotected release on a reef near the mariculture center. In protective cages, clams of this size survived well, and clams released at a shell size of 130 mm required no protection for high survival rates.

Preliminary estimates of potential biomass production capacity in giant clam culture indicate that 16 tons of edible clam meat per hectare per year could be produced. This compares well with mussel culture and exceeds most fish-based aquaculture yields (figure 4.7).

The Palau mariculture center has also developed packing techniques that allow juveniles to be shipped throughout the world with minimum losses.

Scallops

In recent years, methods of culturing scallops that are similar to those for oysters, mussels, and clams have been attempted. Because they are mobile, these bivalves must be caged at relatively low densities. Research is now underway in the United States at the University of South Carolina and the University of Georgia sea grant programs to test the use of suspended lantern nets and polyculture of scallops with fish in ponds. This is a promising area that is likely to be of increasing significance.

Marine Snails

The culture of snails is likely to become a major area of development in mariculture. In most cases, these animals feed on small algae (see discussion above under algal turf mariculture), and the basic requirements are those of providing an algal growth surface and sometimes a protective cage. Wild young have not been a major source of juveniles for these organisms, and the

Figure 4.6
Inspection of the growing mussel crop simply involves lifting the rope out of the water. At harvest time, the rope is untied from the raft and brought to shore. (L. Bell)

basic limitation to developing marine snail mariculture has been that of the hatchery process. Major advances have been made in spawning, hatching, and grow-out processes, but culture has not progressed past the pilot stage. Cage culture for abalone also seems promising, and several organizations in Caribbean countries have been testing larger scale operations. The transition period from the hatchery to grow-out conditions seems to be especially critical, and more work is needed on nursery systems to reduce high juvenile mortality.

Figure 4.7
At 4 months, about 100 giant clams are a handful, but at 3 years it only takes one. Culture in shallow sandy coastal areas and in raceways both give excellent yields. (G. A. Heslinga)

Crustaceans

Extensive efforts over many decades have been made to hatch crabs, shrimp, and lobsters of various genera and species. The larval development process has often proved complex, difficult, and expensive, and is probably not of near-term interest to artisanal fisheries. Marine shrimp hatchery technology is now routine, but crabs and lobsters have yet to be produced under commercial hatchery conditions. However, recent work with the grazing Caribbean king crab (*Mithrax spinosissimus*) has shown promise.

Mithrax Crabs

Mithrax crab eggs are obtained from gravid females caught in the wild or grown in captivity. When the female is about to release her eggs, she is placed in a juvenile cage, where she spawns. The larval crabs grow undisturbed without the mother for 60 days. During this period, the small crabs feed on algae growing on the screen of the box. Between 60 and 100 days after hatching, screens covered with algal turf are introduced into the cages to provide food to the juvenile crabs.

The juvenile crab cage is a wooden frame box, covered with fine mesh (375 micrometers) screen. During the crabs' first 100 days, the cage is anchored about 3 m below the surface in a shallow area with moderate wave action.

After 100 days, the crabs are about 15 mm in diameter and are transferred to grow-out cages fitted with the plastic algal screens for grazing. The growth rate of the crabs depends on adequate feeding and replenishing of the algal screens. Stocking densities must be decreased as the crabs grow and increase their consumption of algae.

Four hundred days after hatching, the crabs will have grown to about 1 kg in weight, 100 mm in length, and will need about one-third of a screen of turf algae per day.

Marine Shrimp

Marine shrimp culture is expanding rapidly in ponds adjacent to estuaries. Pond culture will not be covered in this report, but the enhancement of natural areas with juvenile shrimp has had some success in Italy and Japan. This ocean ranching, where juveniles are raised in the hatchery and allowed to grow out in a natural environment, may be appropriate for certain tropical areas where stocks have been depleted because of overfishing. In this method, it is best to grow the shrimp in transition ponds to bring them to a larger size before release.

INTEGRATED SEA FARMING

Integrated sea farming has been suggested as a possibility for inhabitants of the South Pacific who live by reef foraging. Several precedents exist for this type of activity. The Seruti people in Irian Jaya, Indonesia, live in wooden houses on stilts over the water and raise fish in floating cages. Farmhouses are often built in the *Eucheuma* farm areas, raised on bamboo stilts over the reef flats on which the farms are located. A reef fiat is the ideal location for such an integrated farm. The water is shallow, protected, and productive.

POLYCULTURE

Polyculture is a technique developed by the Chinese for the culture of several aquatic species in the same body of water. The Chinese obtain very high production with several species of carp that feed at different trophic levels in freshwater ponds.

Polyculture in the marine environment has been practiced in Southeast Asia with shrimp and milkfish, and Israel has experimented with mullet and shrimp. Work is currently being done in Hawaii with a combination of oysters, tilapia, and shrimp. The South Carolina Sea Grant Program is working on a combination of clams or scallops with striped bass. Many other combinations are possible and should be considered in any new development project.

RESEARCH NEEDS

The life cycles of many marine species are not well understood. Without this basic knowledge, modern culture techniques are impossible. An increased number of marine animals and plants will inevitably be farmed once husbandry techniques have been developed. Special attention needs to be given to the cage culture of marine fish, a technique that is still in its infancy.

Increased productivity of cultured marine species must be a basic research goal. The environmental conditions for optimal production, as well as the constraints, must be identified and then considered in choosing the most appropriate species and cultivation sites.

Much has been learned in recent research on the control of reproduction and growth of molluscs. In many species of molluscs, spawning is induced by the enzymatic synthesis of prostaglandins. This production of prostaglandin hormones can be initiated by a low concentration of hydrogen peroxide in the seawater surrounding these organisms.

After development to the larval stage, the organism must attach to some suitable surface and undergo metamorphosis. This transformation is also biochemically controlled. Specific chemicals extracted from red algae, for example, will induce abalone larvae to settle and continue their growth to adulthood.

For the oyster *Crassostrea virginica*, bacterial by-products have been demonstrated to induce metamorphosis. Oyster larvae have a preference for surfaces coated with specific bacteria.

In these and other instances, metamorphosis-inducing biochemicals have been shown to originate from some feature of the preferred adult environment. These features can include individuals of the same species, algal or bacterial films, or other plant species that may serve as nutrients for the adult organism.

In addition to biochemical control of spawning, larval settlement, and metamorphosis, research is also in progress on growth enhancement. The use of growth-regulating hormones isolated from mammals has accelerated early growth in abalone, giving increases of about 25 percent over the mean growth rate in the first few days after metamorphosis.

Thus, various biochemicals already present or readily introduced to the environment can serve to benefit marine aquaculture. Research is needed on the identification of more of these materials and methods for their use.

LIMITATIONS

The major drawback to the expansion of mariculture is the need to collect larvae in the wild for stocking many sea-farming systems. Better hatchery techniques for more species are needed. Mariculture systems that are generally located in protected near-shore areas will be threatened by pollutants and siltation unless proper conservation methods are followed. Another consideration is the possible damage or destruction of culture systems by storms or waves.

Control of a coastal area will be necessary for many mariculture systems. Therefore, cooperation with governmental regulating agencies and local fishing communities must be considered.

Fishermen working as sea farmers may require a change in life style that may involve social and cultural difficulties.

Socioeconomic considerations will determine the ultimate success or failure of any sea-farming venture. Fluctuating prices for marine products complicate planning and economic assessment. The materials required for the construction and maintenance of culture systems may not be available at remote sites.

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5

Fish Processing and Preservation

Postharvest losses of fish reach 35 percent, nearly 25 million tons, of the world's fishing catch. The Food and Agriculture Organization of the United Nations (FAO) has estimated that in some developing countries, postharvest losses of fish exceed those of any other commodity, often surpassing 50 percent of the landed catch. The losses are highest in the countries whose populations have the lowest protein intake. Reducing these losses could increase protein availability, improve nutritional status, and eliminate some of the need to import food.

Postharvest losses of fish occur during the numerous steps from catch to market. The lack of appropriate methods to preserve the catch on board results in heavy losses. Additional losses occur in the period after docking and before marketing. During this period, exposure, inadequate processing, and insect infestation take their toll. The catch is further reduced by poor transport to market, unsatisfactory preservation, and further exposure during the marketing process.

This chapter will examine fish processing and preservation between catch and marketing. Some technologically simple preservation and processing methods, which could be adopted at the village level, are described.

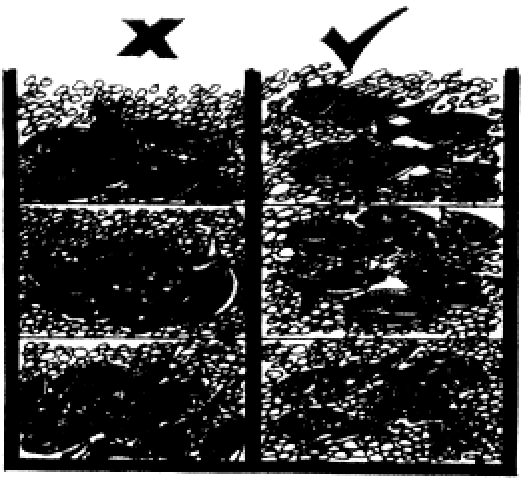

Figure 5.1
For best cooling, fish and ice should be packed in layers.

PRIMARY PROCESSING—ON-BOARD HANDLING

Fresh fish are highly perishable and start to spoil as soon as they are landed. Concern for quality should begin on board the vessel. The first consideration should be to bring the fish aboard alive and in good condition. This is more likely, for example, if gill nets are set for six hours or less and trolling runs are two hours or less.

Fish should only come in contact with clean surfaces. It is important that bacterial contamination be kept low. Keeping the deck, hold, and storage boxes free of fish residues, dirt, and slime with the use of clean seawater and a scrubbing brush should be adequate for this purpose.

Fish should be handled with care. Kicking, trampling, or dumping the fish will increase the rate of spoilage. For high quality, fish should be chilled as quickly as possible to 0°C. Before fish are landed, hot decks should be cooled with clean seawater. Because high temperature is the single biggest cause of quality loss, fish should be moved promptly from the deck to cool storage.

It is most efficient to put the ice and fish together in a covered box or hold area. Flakes or small pieces of ice provide the most effective cooling. Large irregular pieces can damage the fish. Fish and ice should be packed in alternate layers. Dumping ice on a pile of fish will not give good results (figure 5.1).

The sanitary quality of the water used for producing the ice is also important. Both disease- and spoilage-causing microbes can survive in ice and contaminate the catch when the ice melts. Similarly, ice should not be reused. Once used for storing fish, it should not be recycled for cooling freshly caught fish.

For many fisheries, however, it is not practical to use ice—the vessel may be too small, or it may not be possible for the fisherman to recover the cost of ice through higher prices. Where the fisherman is at sea for only a short period, the use of ice may not be necessary. Delays in icing up to about six hours will still give reasonable quality for small pelagic fish, provided the fish are consumed promptly.

Fish can be kept cool by other methods. If possible, the fish can be kept in water in live wells until the boat lands (figure 5.2). Water temperature is usually lower than ambient temperature. Fish kept shaded will be cooler than if they are exposed to the sun. Keeping the surface of the fish wet will help bring the temperature down (evaporation of the water absorbs heat from the fish). It is easier to keep the fish damp if materials such as wet seaweed, leaves, sacking, or sawdust are used as a light covering to increase the amount of water available for evaporation.

Whether the fish are stowed with ice or without, overfilling of containers should be avoided to prevent crushing them (figure 5.3). Cool conditions and careful storage should continue through landing and marketing. Spoilage can never be prevented through chilling or cooling, but the cooler the fish are, the greater the reduction in bacterial and enzymatic degradation. For each 5°C increment in storage temperature above 0°C, there is a significant reduction in shelf life. Fish that can be stored for two weeks at 0°C may only last a day or two at 10°C (figure 5.4).

In some areas, work has been done on ice-making machines that do not require gasoline, diesel oil, or electricity as an energy source.

A biomass-fueled ice-making machine has been developed at the Asian Institute of Technology in Thailand. It requires little maintenance and has no moving parts. Almost any waste biomass can serve as the fuel (figure 5.5). This ice maker uses an intermittent ammonia-water absorption cycle. These refrigeration systems produce their cooling effect through the heat absorbed when liquid ammonia is converted to gaseous ammonia. As liquid ammonia vaporizes, heat is extracted from its surroundings. When this

Figure 5.2
On some boats, it may be possible to keep fish in live wells after they are caught.

Figure 5.3
Overfilling containers and crushing of fish should be avoided.

change occurs in a closed container so that heat is extracted from water, ice is formed.

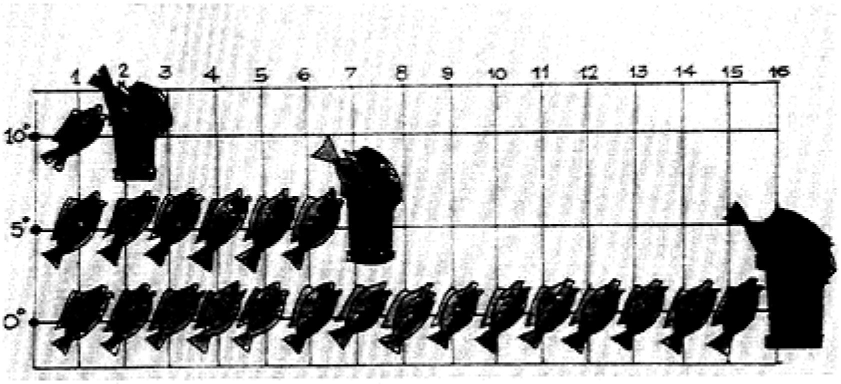

Figure 5.4
Fish that can be stored for two weeks at 0°C may only last a day or two at 10° C before spoiling.

As seen in figure 5.5, fuel is burned in the stove (A) to heat water, which is then circulated through the generator (B) that contains a mixture of ammonia and water. The ammonia is distilled out of the water mixture, passes through the liquid seal (C), and is cooled to liquid ammonia in the condenser coil (D). The liquid ammonia is held in the ammonia receiver (E). To make ice, the liquid ammonia is released into the ice box (F) where it reverts to gaseous ammonia and converts containers of water to ice. The gaseous ammonia is then redissolved in water in the generator (B) and the cycle can start over. The complete cycle takes about 12 hours and produces about 225 kg of ice. The ice maker was built in Thailand at a cost of about US$3,000.

A compact solar refrigeration system that uses the same technology as the biomass-fueled ice-making machine has also been developed (figure 5.6). In this case, the ammonia-water solution is heated in the pipes of a solar collector.

SECONDARY PROCESSING

The purpose of secondary processing is to convert the raw fish into a form that is still acceptable to the consumer and that has a longer shelf life. However, to ensure a high-quality finished product, it is necessary to begin with a high-quality raw product. This, once again, accentuates the importance of primary processes.

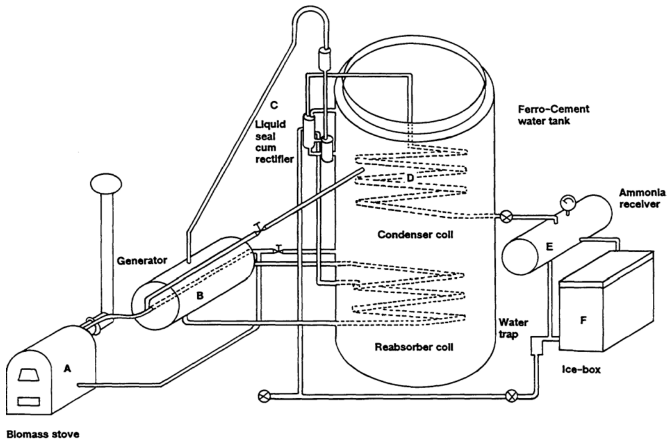

Figure 5.5
This refrigerator can make 225 kg of ice in about 12 hours using biomass as fuel. It has been successfully field tested in Khau Yai, a remote rural island off southern Thailand.

Salting

Whether an end in itself, or as part of a smoking or drying process, salting has been used for thousands of years to preserve marine products. Salting has no adverse effect on the value of fish protein. Bacterial growth can be significantly retarded by the presence of sufficient quantities of common salt (sodium chloride). When fish is placed in a brine solution, the salt penetrates the fish, and water is extracted from the tissues by osmosis. At a salt concentration of 6-10 percent in the fish, the activity of most bacteria that cause spoilage will be inhibited. Since fish contain 70-80 percent water, the amount of brine used must be adjusted accordingly. The higher the salt concentration in the fish, the longer its storage life. Several methods of salting are commonly used: dry salting, kench salting, brine salting, and pickle salting.

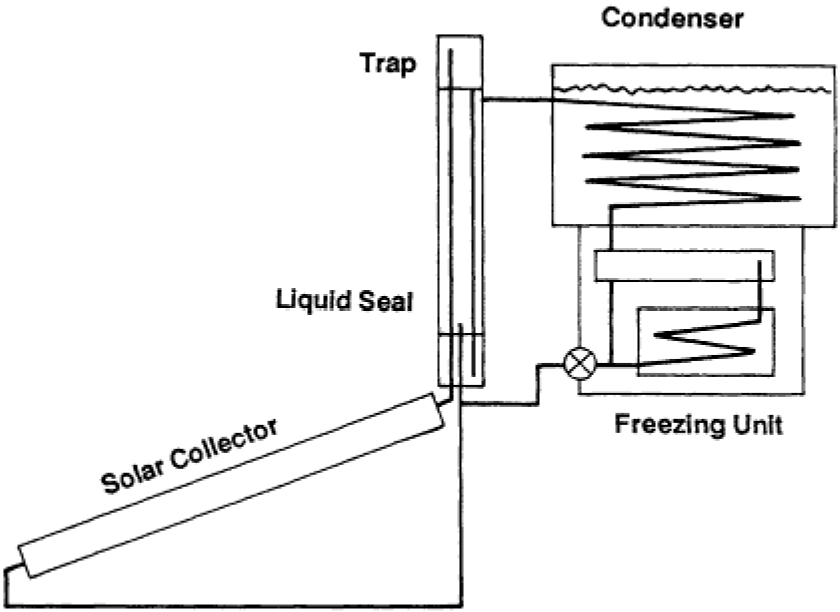

Figure 5.6
A solar-powered icemaker has also been tested in Thailand. During the clay the sun's heat is used to produce liquid ammonia. At night the liquid ammonia is used to produce ice—about 40 kg in a 24-hour cycle.

Dry salting is the simplest method and is used primarily for fish with high water content. Granular salt is rubbed onto the outer and inner surfaces of the fish. Kench salting is a similar method that involves stacking split fish and layers of salt. The pickle or liquid formed is allowed to drain. In Brazil and India, sardines are preserved by pressing and salting. Avoiding air exposure is almost impossible in these dry-salting processes. However, wrapping the product in a plastic bag reduces contact with the air.

The wet-salting methods (brine and pickle) are recommended for tropical applications, especially with fatty fish. In brine salting, the entire or split fish is immersed in an aqueous salt solution. An 80-100 percent saturated brine solution (270-360 g of salt per liter of water) is preferred. For strongly cured fish, about 30 g of salt per 100 g of fish is needed. During processing, the brine solution will become diluted as water is drawn from the fish, and additional salt will be needed. Plastic or wooden barrels can be used for brine treatment. The largest fish should be able to lie flat in the container. A wooden lid, which can be weighted, should be employed to ensure that the fish are submerged in the brine solution.

Another wet cure is pickle salting. The fish are covered with salt and placed in layers with salt between the layers. Since a watertight container is used, the brine that is formed begins to cover the fish. If the fish are not completely covered within 3-4 hours, saturated brine is added to cover them. A lid is placed over the fish to ensure that they are completely submerged in the liquid. At least 10-24 days are required for complete curing.

Halophilic or salt-tolerant bacteria or molds may grow on incompletely dried salted fish or on dry salted fish that have Become moist. However, pickle-cured fish are free of growths of halophiles, because these organisms are aerobic, and the brine of pickle-cured fish does not contain sufficient oxygen to support their growth. This oxygen-poor environment also reduces rancidity in fatty fish.

Drying

Much of the fish in rural areas of the tropics is preserved by sun drying. While the cost of sun drying is low, there are significant losses due to spoilage, contamination by dust, and insect infestation, particularly when the fish are laid close to the ground. As a first step, raised structures would reduce contamination from some wastes and insects.

Solar fish driers are simple and inexpensive and can eliminate much of the spoilage that occurs with traditional drying methods. These driers usually have a wood or bamboo-frame table, covered with plastic or glass to produce an enclosed chamber (figure 5.7). The surface of the table can Be covered with black plastic or paint to absorb the sun's heat. With openings at the top and bottom of the drier, air will be heated and flow around the fish. Fish exposed to this flow of heated air will rapidly lose moisture, reducing drying time by as much as half over open-air drying. Similar driers have been constructed in Bangladesh, Indonesia, Rwanda, the Philippines, and Papua New Guinea. Solar driers have a number of advantages over traditional drying methods. They exclude rain, insects, animals, and dirt, and can produce temperatures high enough to reduce the possibility of mold or bacteria spoilage.

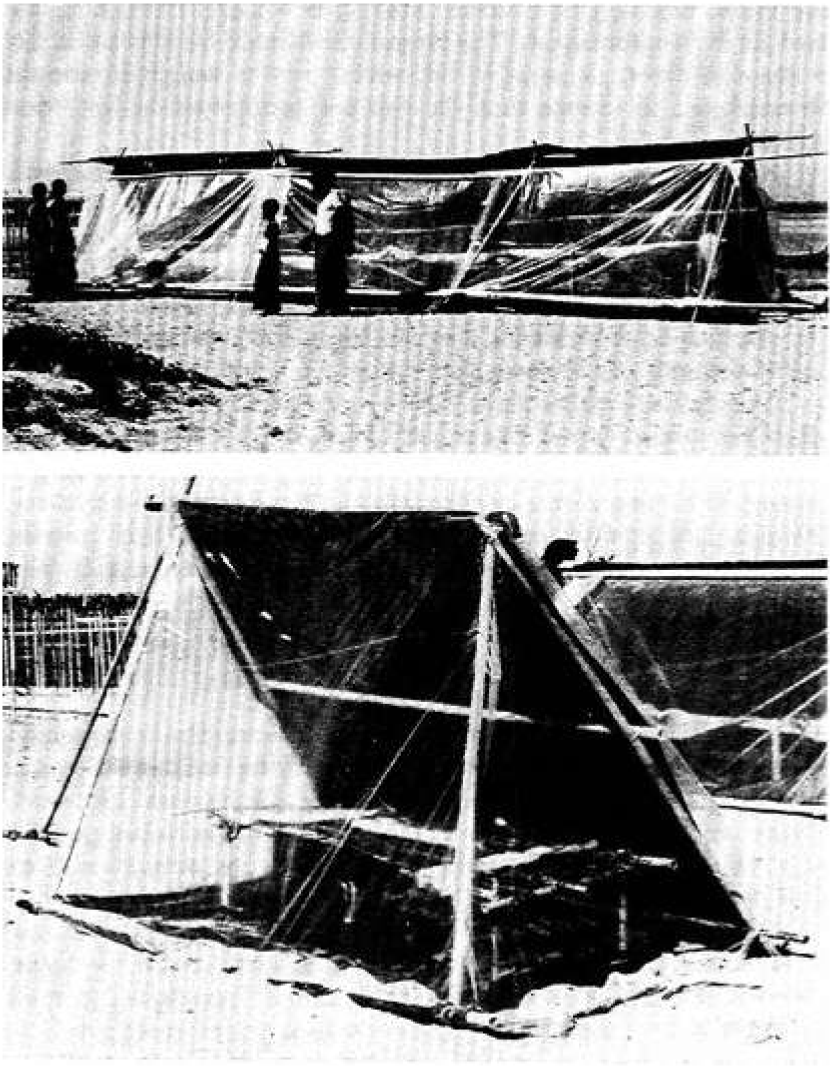

Figure 5.7
In Bangladesh, solar fish driers are constructed from bamboo, twine, and plastic film. (P. E. Doe)

A wide variety of designs for solar driers has been developed. Most require only inexpensive, readily available materials. In addition to plastic film and bamboo, discarded oil drums, scrap wood, thin metal sheeting, and even mud may be used.

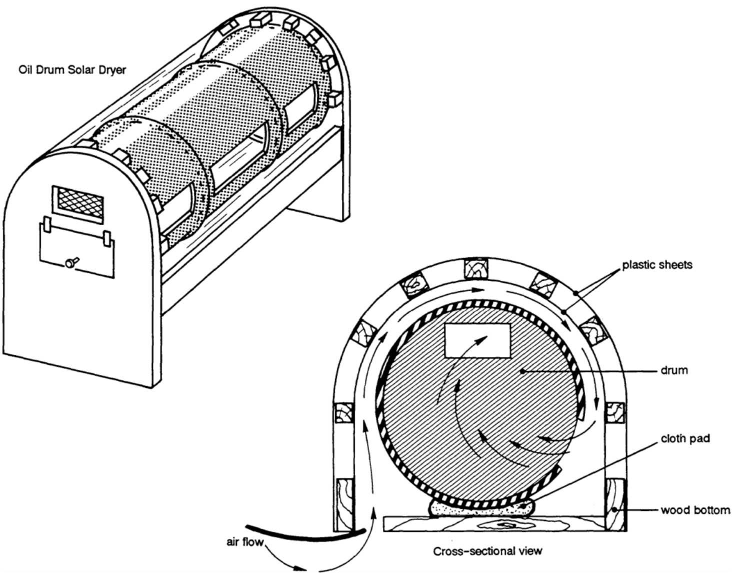

Figure 5.8
A solar drier can also be made using an oil drum with a wooden frame and plastic sheeting.

An oil drum solar drier has a creative design (figure 5.8). The ends of the drum are removed and three rectangular ports are cut in the side. The drum is mounted on a wooden frame that includes air vents and access doors on both ends of the drum. Two sheets of clear plastic enclose the drum. These allow sunlight to heat the drum and, because of the air space between the two sheets, provide insulation to retain the heat. The outside of the drum is painted black to absorb solar radiation and the inside is painted white. Cool air enters the base of this unit and is heated as it passes between the exterior of the drum and the plastic sheets. This heated air then enters the drum through the rectangular ports and passes over the trays of fish in the drum and out through the vents at the ends of the drier.

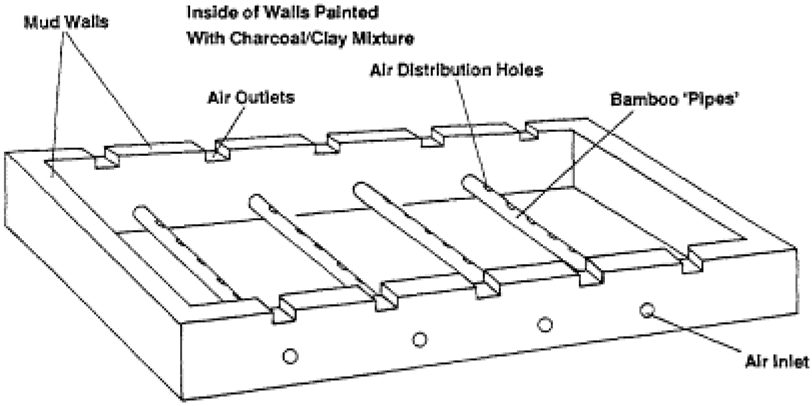

Figure 5.9
In Tanzania, a solar drier is constructed from mud and bamboo. When in use, fish are placed on the bamboo supports and transparent plastic covers the top.

A mud wall solar drier has been developed in Tanzania. A rectangle of clay walls is constructed and, while the mud is wet, bamboo tube vents are inserted at 50-cm intervals from side wall to side wall (figure 5.9). The bamboo tubes have a number of small holes so that air can flow into the drier. Fish trays are placed on top of the bamboo tubes and openings are cut into the top edge of the wall to exhaust the heated air. The inside walls and bottom of the drier are plastered with mud that is mixed with charcoal powder to absorb the heat. In addition, a layer of dark-colored stones can be placed in the bottom of the dryer to provide heat storage. The roof can be a transparent plastic sheet or film.

A solar dome dryer (figure 5.10) has been developed and tested in Aden. Designed on the basis of results with solar tent driers, this large unit has a capacity of about 1 ton of prepared fish. In drying tests with local fish, moisture contents of 20-25 percent were obtained. Typical sun-dried fish in this area had a moisture content of 25-35 percent. Use of the solar dome dryer also significantly reduced contamination from insects, animals, and dust.

A solar collector can also be attached to a cabinet drier (figure 5.11). The solar plate collector uses black coated, corrugated metal to absorb the radiation. This is covered by a double panel of glass or plastic to insulate the warm air inside the collector. Air passes on both sides of the metal collector, becomes heated, and flows into the upright cabinet drier and through the trays. The optimum angle for the collector panel must be determined by experiment.

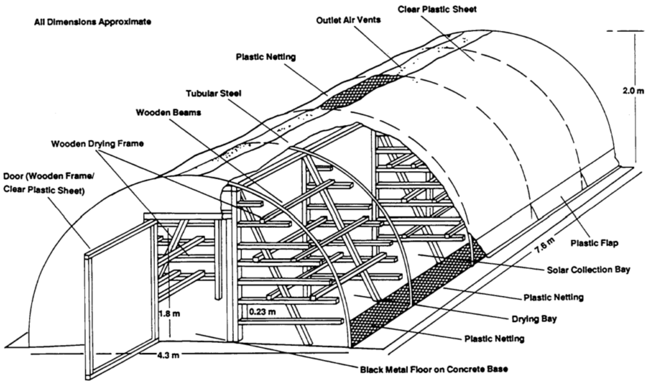

Figure 5.10
In Aden, this large solar drier can hold about a ton of fish.

The solar agrowaste-fueled drier was designed and constructed in the Philippines (figure 5.12). It has the advantage of utilizing alternative energy resources in the absence of solar heat. The drier has both a solar booster and furnace. It has a capacity of 170-200 k g of fresh fish.

The body of the drier is trapezoidal and is made of wood or aluminum frames covered with polyacetate film. Black film covers the bottom of the drier. The side walls have up to 4 doors that allow 14 trays (114 × 53 cm) to slide into the drier. Woven nylon screen is used to line the bottom of the trays. The top portion of the back wall has several screened warm-air outlets.

A small stove can be connected to the drier. Charcoal or agricultural waste materials can be used as fuels in the stove furnace. Warm air from the stove is regulated with a shutter so that only heat enters the unit while fumes are excluded.

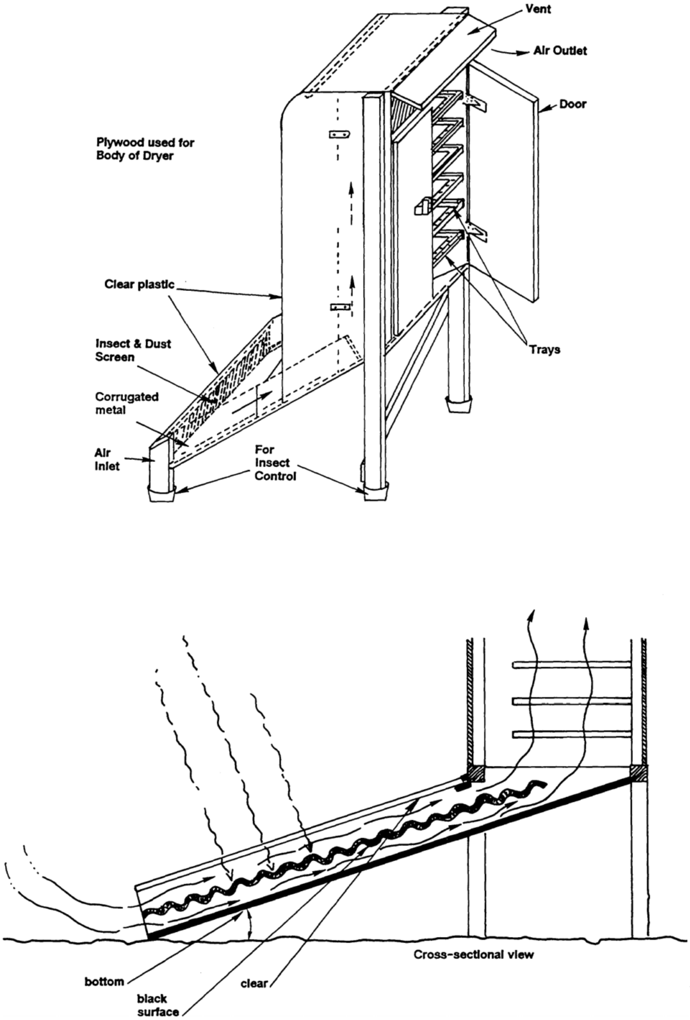

Figure 5.11
A solar collector can be attached to a cabinet drier to provide a flow of warm air for drying fish.

Various drying schemes are possible. The solar system may be used alone or simultaneously with the stove. Alternatively, the agrowaste system may be operated alone in the absence of solar heat or solar heat can be used during the day and agrowaste drying at night.

Other models of low-cost fish driers use only agrowaste as fuel. The agrowaste fish drier (figure 5.13), developed by the College of Fisheries of the University of the Philippines in Visayas, burns coconut husks, firewood, or rice hulls. The trays in the drier can hold up to 100 kg of fresh fish.

At the base of the structure is a furnace made of hollow blocks, with inside dimensions of 0.90 × 1.20 × 0.85 m. An exhaust tube carries smoke and gases outside the system. The furnace and drying chamber are separated by a corrugated, galvanized iron heat guard. This guard has a 20-cm opening through which the hot air can pass into the drying chamber that contains 25 trays. Air vents are adjusted to ensure an optimum drying temperature of 55°-60°C.

Smoking

Smoking is another traditional preservation technique that is used to prepare fish products with long storage lives. Smoke contains substances that kill bacteria, thus helping to preserve the product. The heat also dries the fish. Often fish are salted before they are smoked. In tropical countries, fish are generally heavily smoked at relatively high temperatures so that they are also cooked.

In hot smoking, temperatures may remain between 60°-110°C for 4-12 hours. This is usually long enough to eliminate the non-sporulating spoilage bacteria. However, the spores of *Bacillus subtilis* and *B. mesentericus* survive even with longer periods of smoking. The bactericidal action of the smoke is considerably increased by the presence of salt in the fish.

In simple smokers, fish are laid on trays or hung in the column of smoky air above the fire. The traditional Ghanaian mud oven is cylindrical, with a thatched cover (figure 5.14). The oven consists of layers of mud about 2.5 m high and 10 cm thick. Grill bars are installed at about 1 m off the ground. The fish, placed on the grill bars, must be regularly turned to encourage even drying and smoking. A stokehole is located in the base wall.

Figure 5.12
A small stove can be connected to the base of a solar fish drier. By burning agricultural wastes or charcoal in this stove, drying can be accelerated.

A variation of the mud stove involves using 250-gal steel drums instead of mud for the construction of the cylinder (figure 5.15). The drums are cut along their length and rejoined to form a larger cylinder. Fish are smoked on grills within this cylinder.

The Ivory Coast kiln (figure 5.16) is efficient and simple and has had a degree of acceptance, even though it deviates from traditional designs. The base of the kiln is 2 × 2 m and is about 1 m high. The sides are sheet metal or corrugated zinc, nailed to wooden support posts in the four corners. A steel drum, with a hole cut about one-third of the way down the side, is laid horizontally through one of the kiln walls. The fish trays are stacked on top of the oven.

Another improved oven is an agrowaste fish drier and smoke chamber, developed in the Philippines (figure 5.17). The chamber is made of sheet metal and has three doors in the front where trays can be inserted. Charcoal or agrowastes are burned in the combustion chamber in the back of the smoker. After circulating through the drier, the smoke exits through three exhaust valves into the top of the structure.

The Chorkor smoker (figure 5.18) is gaining acceptance by West African women involved in traditional fish smoking. The design, based on traditional smokers, has a long life, low construction cost, and low firewood consumption. The capacity of this smoker is large; up to 18 kg of fish can be smoked on each tray, and as many as 15 trays can fit on an oven.

The ovens are rectangular and about twice as long as they are wide. There is a dividing wall in the middle, two stokeholes in the front, and a fire pit in each chamber. The walls are made of clay mud, cement, or clay blocks. The top of the walls must be level so that the wooden-framed trays can rest snugly against them. The oven should be low, but the fire ought to be at least 60 cm below the lowest tray. The wooden frames of the drying trays rest on the edge of the oven walls and therefore do not catch fire. These trays effectively form a chimney above the fire in which heat and smoke constantly circulate.

Small and medium fish may be smoked whole or split; large fish are cut into fillets. This smoking process yields a product with 10-15 percent moisture content and may require from 2 hours to 2 days. Fish smoked with the Chorkor smoker can be stored up to 9 months in the tropics if the trays are tightly covered with plastic,

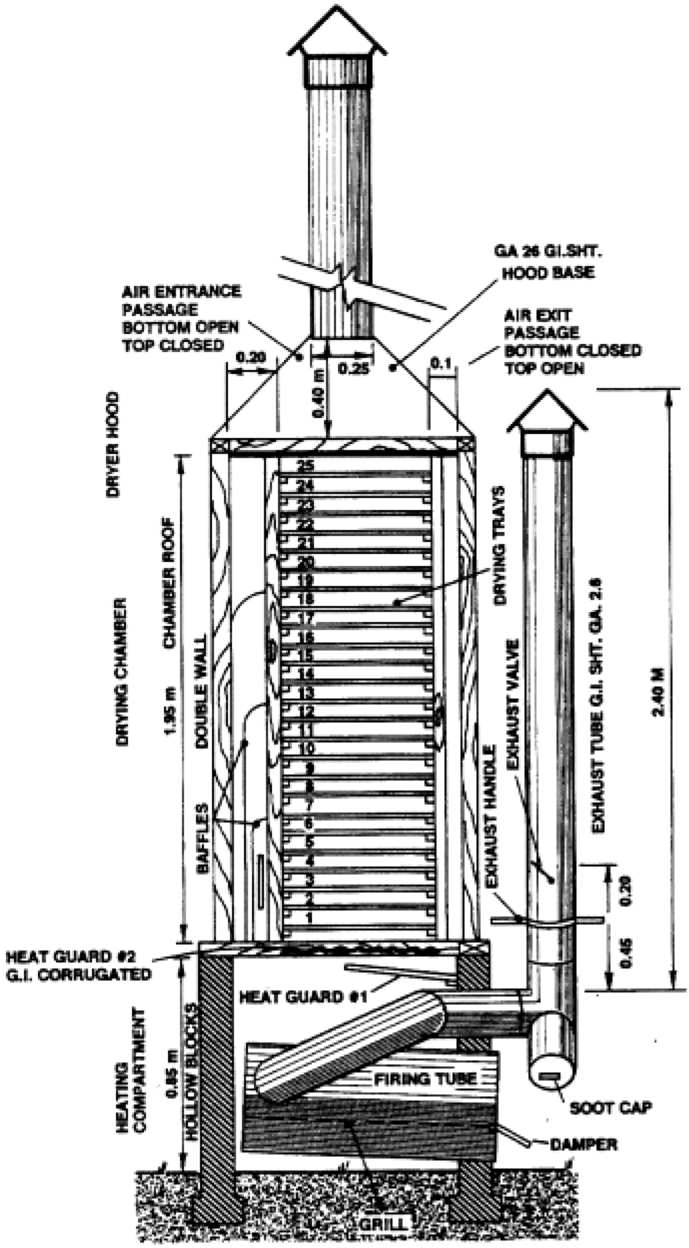

Figure 5.13
In this drier, the smoke from the burning fuel is diverted outside the unit while the heat passes up through the trays of fish.

Figure 5.14
A traditional mud oven for smoking fish is difficult to operate and has a limited capacity. (B. Brownell and J. Lopez)

Figure 5.15
An oven made from two steel drums is more durable than one made of mud but is equally laborious to operate. (B. Brownell and J. Lopez)

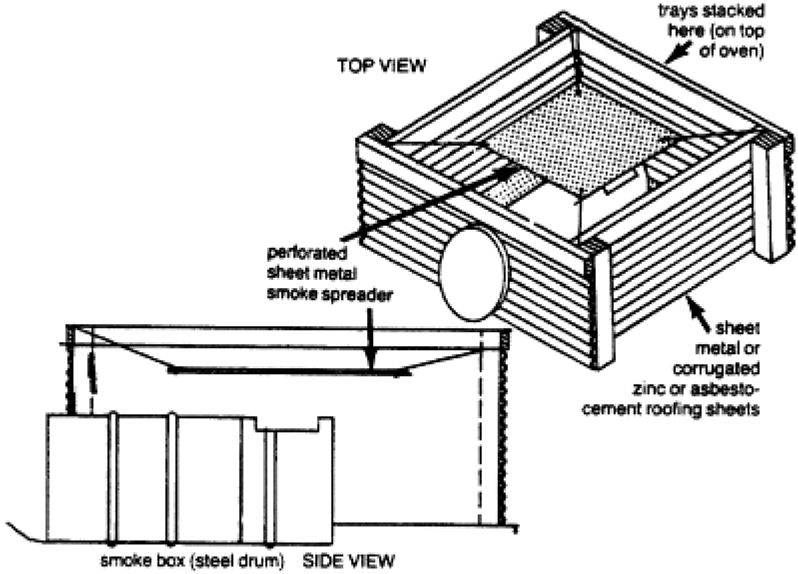

Figure 5.16
The Ivory Coast kiln is simple and efficient but the construction materials are costly.

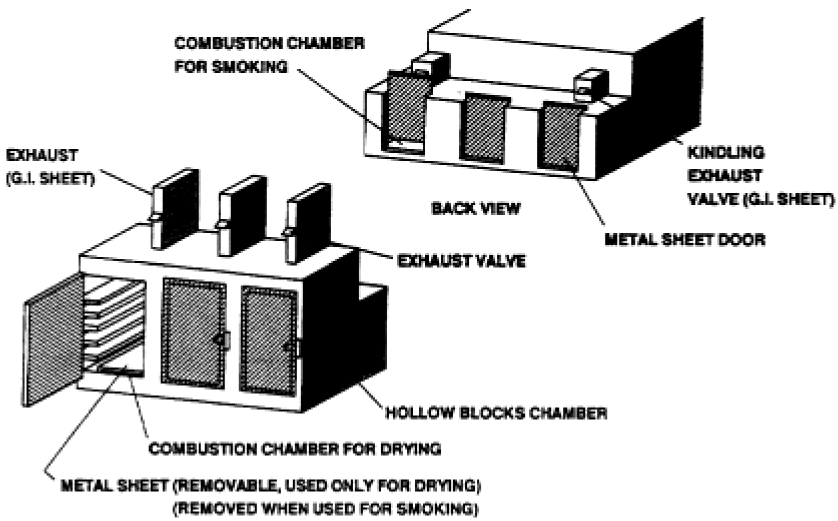

Figure 5.17
In the Philippines, an agrowaste fish drier and smoker has been developed. This unit is made of hollow concrete blocks with sheet metal doors and chimneys.

brown paper, or banana leaves. The fish should be resmoked every 2 months to eliminate mold, bacteria, and insect larvae.

Fish Paste Products

Kamaboko is a popular fish paste product made from *surimi*, a washed minced fish common in Japan since the fifteenth century. Codfish, croaker, lizard fish, and conger eel have the texture necessary to produce *surimi*.

To prepare *surimi*, the head and viscera are removed, the fish are cleaned in water, and the bones and skin are removed. *Surimi*, the minced meat, is then washed repeatedly with cold fresh water to produce a bland and functional meat. The *surimi* is then chopped in a cutter for 4 minutes while 30 g of salt per kg of fish are added. Next, potato or wheat starch is added (100-250 g per kg of fish), and the mixture is chopped for 10 minutes longer. Sugar (30-100 g per kg of meat) and chopped vegetables may be added before a final 5 minutes of chopping. The resulting paste is then shaped and cooked in a variety of ways.

Kamaboko is produced by shaping the surimi paste into half cylinders, like loaves of bread, on wooden blocks. The loaves are steamed at 85°-90°C for 40 minutes and then cooled for 2 hours in air. The products are packaged in cellophane and have a shelf life of I week in warm weather.

If the *surimi* paste is shaped into semicircles or squares, steamed at 90°-95° C for several minutes, and cooled on a grid, a product called *hanpen* is obtained. The *surimi* may also be shaped into a ball or cake and fried to produce *satsuma-age*. If it is shaped into a tube and steamed, it is called *chikuwa*.

In Taiwan, fish balls are made from fish paste. Shark, lizard fish, pike, eel, and marlin are the main species used. It is shaped by hand, made into balls, and then steamed.

One advantage of these fish paste products is that the raw materials are not recognizable. Therefore, low-priced fish or fresh species that are disliked can be utilized.

Boiled Fish Products

Boiling fish in water, as a method of short-term preservation, is accepted throughout Southeast Asia. This method may have

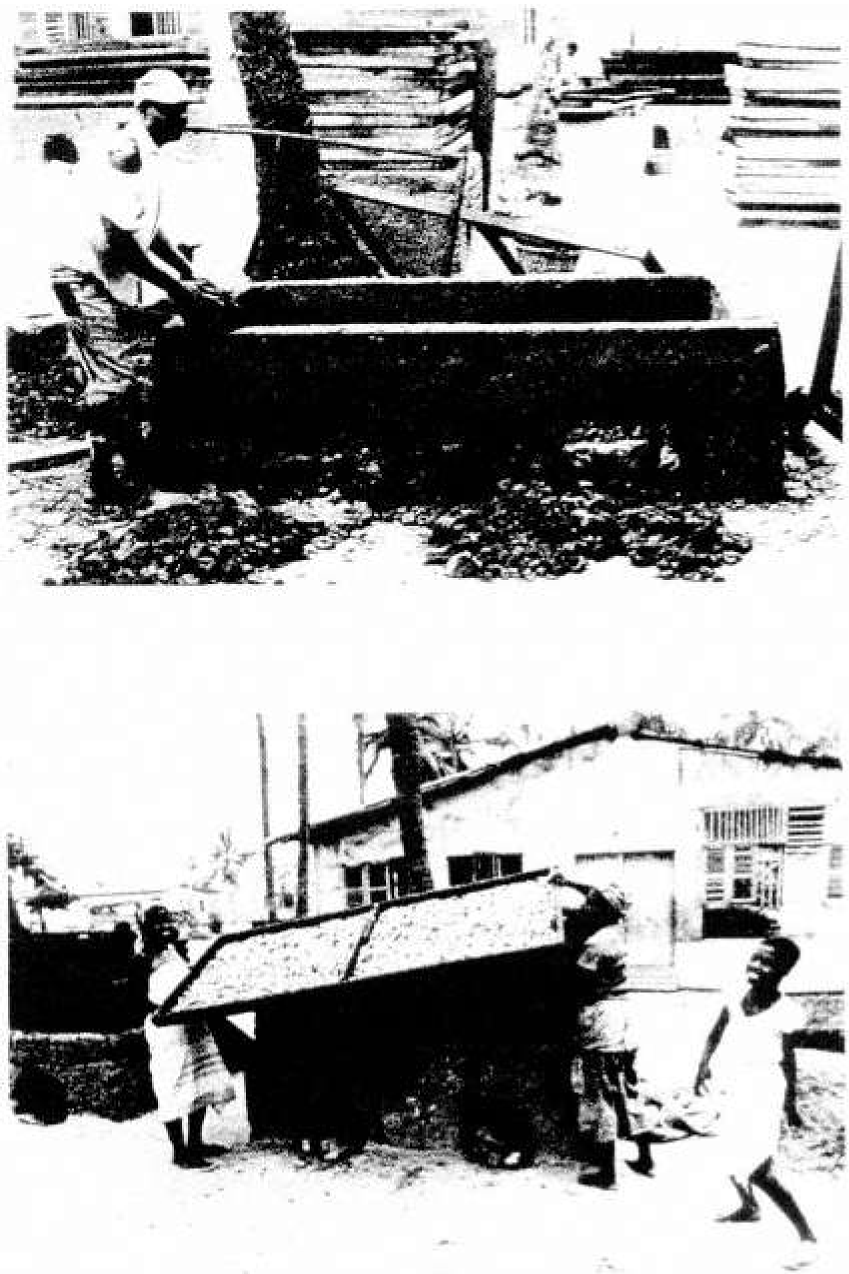

Figure 5.18
The Chorkor smoker has a number of advantages including low construction cost, long life, large capacity, and ease of operation. In the top photo, a mason places a top layer of clay mud on a new oven.

applications in other tropical areas where high humidity and rainfall during part of the year make drying difficult. Boiling could allow distribution of the catch to market with low-cost equipment and facilities.

Boiling denatures the fish proteins and also eliminates many of the bacteria present. Therefore, such treatment may extend the shelf life of the product. Salt may also be added before, during, or after boiling to help retard spoilage.

In Indonesia, boiled fish products are known as *pindang*. Many species, including shark, may be used. The fish are gutted, washed, and arranged in clay pots or metal bowls, with alternating layers of salt and fish. A little water is added, and the fish are heated until nearly cooked. Most of the liquid is drained, more salt is added, and the fish are heated again until no free water remains. The top of the pot is sealed with leaves or paper. Shelf life may range from a few days to 3 months, depending on the amount of salt and the container seal.

Fermented Products

In many Southeast Asian villages, rice and fish are the primary foods. Since both are relatively bland, a long tradition of preparing more flavorful products through fermentation of fish and shrimp has developed.

Since these products are generally derived through hydrolysis in the presence of high salt concentrations, they have good keeping qualities. The nutritive value of the fish or shrimp is retained and the processes are relatively simple. In some cases, the fish or shrimp retain their original form, but usually the end product is a liquid or paste.

Bagoong is a Philippine fermented fish or shrimp paste. *Bagoong na isda* is the fish derivative, dark gray in color with a cheeselike flavor. *Bagoong na alamang* is a thick paste obtained through shrimp fermentation. Although pieces of the shrimp remain, the characteristic aroma of raw shrimp is no longer detectable.

Bagoong na isda is prepared by mixing three parts of fish with one part of salt and enclosing the mixture in a fermentation jar. With occasional stirring to keep the salt concentration uniform, the fermentation is complete in 60-90 days. The corresponding shrimp product is made in the same fashion, but the fermentation is complete in only 3 days.

Nuoc-mam is a clear brown liquid, rich in salt and soluble nitrogen compounds, with a distinctive odor and flavor. It is produced in most coastal regions of Vietnam from small sea fish. More recently, production of *nuoc-mam* from freshwater fish has increased greatly. Traditionally, the fish are kneaded, salted, and placed in earthenware pots that are tightly sealed and buried in the ground for several months. When opened, the supernatant liquid (*nuoc-mam*) is carefully decanted. Except for histidine, *nuoc-mam* contains good concentrations of the nine essential amino acids. Although not a good source of the B vitamins, it is a valuable supplement to cereal diets through its content of other vitamins and minerals. Similar methods are used to produce *nam-pla* in Thailand and *patis* in the Philippines.

In the Philippines, fermented rice and fish mixtures known as *buros* are popular. These are prepared by mixing cooked rice and fish or shrimp with salt and allowing the mixture to ferment for up to 7 days. The products become acidic due to the action of lactic acid bacteria and have a shelf life of about 2 weeks at ambient temperatures (figure 5.19).

In Korea, the fermented fish product *sik-hae* is widely consumed. Flat fish are eviscerated, sliced, salted overnight, and then mixed with cooked millet, red pepper powder, and garlic and fermented at 20°C for 2-3 weeks. The pH of *sik-hae* drops quickly to 4.5 due to the organic acids formed from the millet by the lactobacillus. After fermentation, the product can be stored for up to 1 month at 5°C.

Indonesian *trassi* is a paste made from small shrimp. Interestingly, its production starts on shipboard. When caught, the shrimp are mixed on deck with about 10 percent salt. On shore, the mixture is respread and more salt is added. After exposure to air and sun for 1-3 days, the moisture content drops to about 50 percent and the foul odor disappears. The mass is kneaded and redried and red colorants are added. *Trassi* has excellent keeping qualities. It is often mixed with Spanish peppers to give a spicy product called *sambal*, which is consumed with rice. The Colombo method of curing is used in South Kanara, India, to ferment mackerel. The fresh fish are gutted, washed, and rubbed with salt (ratio 1:3). After the fish are put in cement tanks, the fruit of a small evergreen tree *Garcinia cambogia*, similar to tamarind, is added

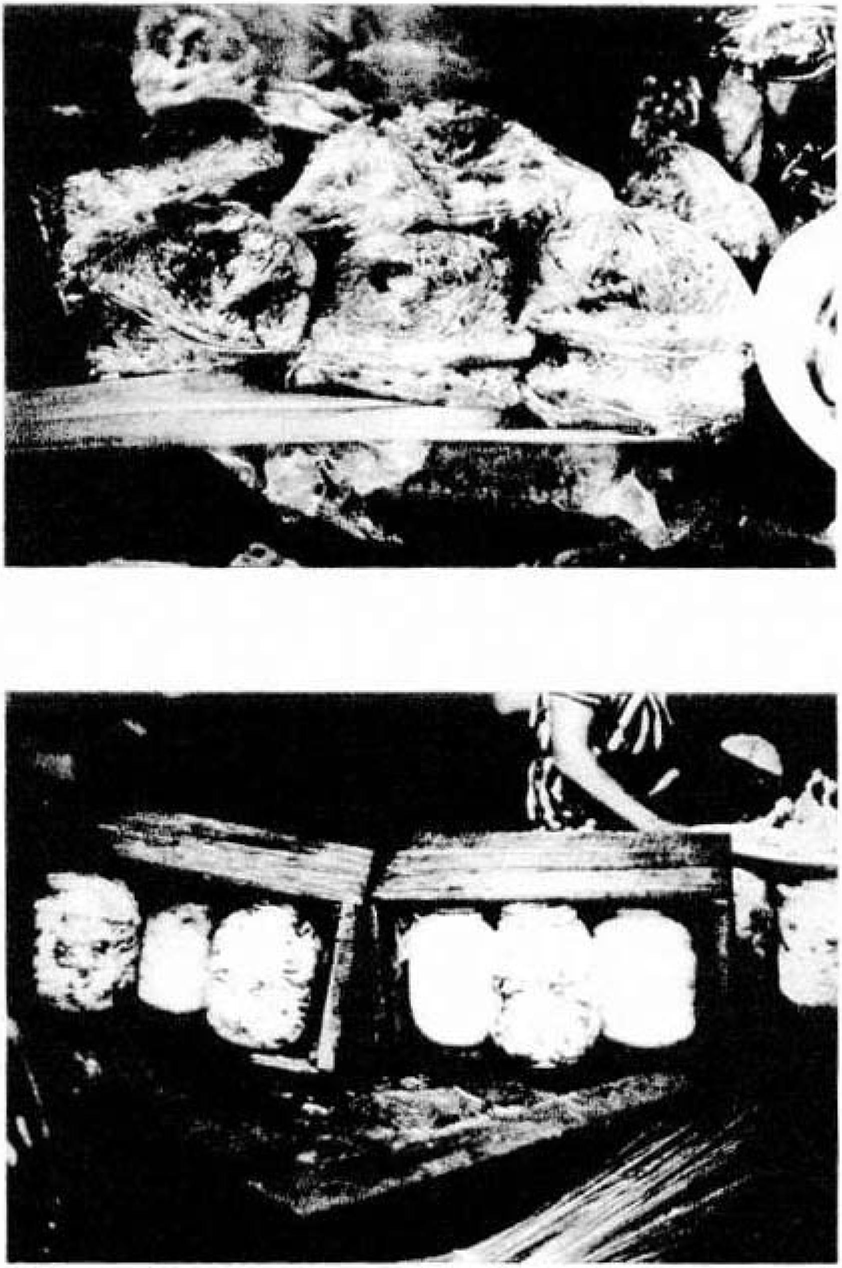

Figure 5.19
Cooked rice and fish are fermented to produce buros, a popular food in the Philippines. (A. Reilly)

(8 kg of fruit per ton of fish). The fish are left for 2-4 months in the brine that forms and are exported in wooden barrels. They can be consumed for up to a year.

In Aden, the same mackerel species is similarly salted in cement tanks, but the brine is allowed to escape. The fish are sewn into palm leaf bags and exported to East Africa.

Fish silage has also been studied as a source of protein for poultry and swine. The starting materials are fish-processing wastes or trash fish and a carbohydrate such as starch or molasses. These are inoculated with a lactic acid bacteria and fermented for 4-7 days before being fed to pigs or chickens.

RESEARCH NEEDS

Ice is desirable for preserving fish and would enjoy more widespread application if its manufacture were economically feasible. A simple, efficient, and economical technology for ice production using nonpetroleum fuels needs to be developed. Alternatively, more efficient and economical driers and smokers must be developed for application in Third World coastal villages.

There is a continuing need for research in the development of new fish products that are acceptable to the local consumers and that will increase storage life. Underutilized fish, especially shrimp by-catch, are obvious targets for product development.

Country-specific studies are needed to provide more precise information on losses during the various stages from capture to marketing. This information could help reduce postharvest losses while increasing protein consumption without increasing the catch.

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