Mariculture and fisheries: future prospects and partnerships

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World fisheries production has levelled off in the latter part of the 20th century and an increasing percentage of the total is coming from mariculture. The prospect of continued depressed yields from ocean fisheries, coupled with increased demand for seafoods, ensures that mariculture could equal production from the harvest of wild stocks in the early part of the 21st century. Mariculture includes a wide range of practices with various degrees of human intervention. Restocking involves the liberation into the wild of larval or juvenile forms and their subsequent harvest in the wild. The success of restocking hinges both on understanding the biology and on the accrual of benefits to those incurring the costs. Fish farming involves holding organisms until they are marketed. Success depends on a large number of factors, with food costs and labour costs being critical. The world is currently witnessing an explosive growth, particularly in the intensive culture of high-valued species for sale in export markets. Ensuring the supply of young fish is a central question for management of wild stocks, for restocking and for the operation of fish farms, and for the interrelations between them. Extensions of range of various species, both planned and inadvertent, have created some new fisheries, but have also generated concern for their effects on native stocks. Predictions for the future include increased mariculture production, emphasis on research on recruitment, seaward movement of farming operations, concern for pollution, and multidisciplinary systems approaches in mariculture research.

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Introduction

The 20th century has witnessed a remarkable evolution in world fish production. At the beginning of the century, the newly industrialized nations were busily using their newly gained technologies to enhance their skills at catching fish. As demand for fish increased, they went further to sea in larger and more powerful vessels to bring bigger loads back to port. As the technologies of refrigeration and on-board processing were refined, the vessels went still further to sea until, by 1970, there was scarcely a stock of fish in the world that could be fished commercially that was not being exploited. And because the fish stocks were owned by nobody until they were caught, there was intense competition to be the first to catch them.

It has often been remarked that the only two things in life that are certain are death and taxes. Those of us who have spent our lives in the study of fisheries would add a third inevitability - overfishing. The great majority of stocks of commercially valuable fish, invertebrates, or mammals in the world have been overharvested within the last century. Recognizing, among other things, that what everybody owns everybody will abuse, the nations of the world agreed to assign to individual nations exclusive fishing rights within 200 miles from their shores, or, failing that, to half the distance from their shore to the shore of another nation. The fish remained a publicly owned resource, but to a public that was smaller and potentially more manageable. But, as had been foreseen (e.g. Larkin, 1970), even this potential was denied for many stocks of fish that migrate across what became boundaries of national exclusive fishing zones, migrating either through the exclusive fishing zones of more than one country, or beyond the exclusive fishing zones into international waters, or both through zones and beyond them. Evidently, it will be some time before the problems of management for these stocks will be resolved, if ever. Meanwhile, overharvesting continues.

There is perhaps somewhat more reason to expect progress in fisheries management for stocks that are confined within a national fishing zone. In consequence, since 1970 there has been renewed and extended discus-
sion of, and some novel experimentation with, methods of limiting the number and power of fishing vessels and the catch quotas they are entitled to land.

There are still few examples of unqualified success. The accelerated pace of science and technology steadily improves capabilities for finding, catching, and processing fish, invisibly changing the power of a fishing fleet. Continued arguments about allocation of portions of the permissible catch to various participants in a fishery (e.g., see Grover 1980) create strong pressures that lead to taking unjustifiable management risks. There seems to be no end to the ingenuity of fishermen in subverting the intent of regulations designed to limit catch. And then there are the questions of social context which ensure that it is a very brave politician indeed who will tell his constituents that they must lose their livelihoods in the interests of conservation or economic efficiency.

As if this were not enough to contend with, the realities of fishing gear usually mean that the targeted species is not the only one caught, and the realities of nature usually mean that the catch of one species has implications for the abundance of other species. The multi-species problem, which embraces both issues as a challenge to management, is enormously complex. The recent Dahlem conference (May 1984) and the review of tropical fisheries management (Pauly and Murphy, 1982) provide good insight into the discouraging prospects for understanding the processes involved.

And so it is that the world catch of naturally produced fish is now much the same as it was 20 years ago, and shows every prospect of remaining at about the same level, or less, for many years to come.

Meanwhile, there are ever more people who wish to eat seafoods, preferably fresh. How to do it at affordable prices? This problem was solved many centuries ago by the low cost culture of fish and shellfish close to the place where they were to be consumed. These ancient practices have usually been (and still are) a component of a way of life combining agriculture and aquaculture (Pullin and Shehadeh, 1980) in subsistence farming that produces crops for local consumption. In other instances, particularly coastal areas, the culture of marine organisms has been combined with artisanal or small-scale commercial fishing in what are often called “cottage industries”.

In recent years, four things have taken place that have enhanced yields from these traditional labour-intensive pursuits and added to them a larger-scale, technology-intensive, mariculture that promises to become a major world food business enterprise. First, a great fund of empirical knowledge has been tested and shared. At the same time, much new knowledge of physiology, nutrition, behaviour, disease, and genetics has been brought to bear on the problems of production. Second, the demand for seafood has increased, not only because there are more people, but also because nutritionists have encouraged the eating of seafoods. Third, methods of handling, processing, and storing have been much improved. Fourth, transportation, both regionally and globally, is cheaper, faster and more reliable than ever before.

Thus, the techniques of aquaculture for the species traditionally raised have been substantially enhanced technologically; the culture of some highly valued species has been scaled up to significant commercial levels, and interest has been aroused in the potentials for culture of many species and varieties that have not previously been cultured.

The broad trends currently underway seem certain to continue. Within only a few decades, cultured production of marine and freshwater organisms could exceed that from harvesting wild stocks. The pastoral revolution on land is being re-enacted at sea.

The scope of mariculture

There is no convenient sharp dividing line between mariculture and the harvesting of wild stocks of marine organisms. Feeding pellets to a domesticated strain of Pacific salmon in a container in which seawater is recycled would certainly be mariculture and akin to the way in which much poultry is now produced. Placing the fish within a netted enclosure in the ocean is akin to farmyard poultry practices of a generation ago. Collecting eggs in the wild and raising the salmon to the smolt stage and then releasing them into the wild is akin to North American cattle ranching of more than a century ago, with the difference that it is not feasible to brand all the fish to indicate to whom they belong. Also, it is difficult to enforce rules about rustling, especially by nationals of other countries, if the fish go beyond the exclusive fishing zone. The point is, ocean ranching is a form of mariculture, even though the period of culture may be only a small fraction of the lifespan.

Parallels can be drawn for many other species. For example, it has long been common practice to grow shrimps and fishes such as milkfish (Chanos chanos) in lagoons, relying on natural sources of recruitment. Further steps toward culturing may be the addition of fertilizers, exclusion of unwanted species, regulation of water levels, and addition of food. Similarly, culture of various sessile marine organisms, such as oysters, may be based on recruitment from the wild, or from spat produced in hatcheries. Mariculture thus covers a wide spectrum of activities which differ only in the degree to which human intervention removes some of the uncertainties of natural production.

Similar arguments can be pursued for freshwater aquaculture for which stocking trout (for example), has been a long-established practice that could be called “ranching” of lakes and streams. Transplanting fish from one place to another, lake and stream fertilization,
hatchery practices, and the techniques of pond fish culture intergrade into a continuum of aquacultural activities.

These parallels are scarcely surprising. Freshwater and marine environments are themselves a continuum in which there are all intergrades of salinity. Culturing in either environment deals with living materials that set the limits and opportunities for human intervention. Both are vulnerable to the uncontrolled vicissitudes of the environment as well as to the impacts of other human activities. Both draw upon a common fund of previous experience and current research to guide their development in the future.

The remarks that follow are focused on large-scale, commercially oriented, technology intensive mariculture. There is no doubt that freshwater aquaculture and small-scale, subsistence-oriented and labour-intensive mariculture will continue to be important on local scales, particularly in rural areas. But to provide for the seafood demands of the highly urbanized world population of the future, only large-scale operations hold promise of filling the gap between demand and supply. With this choice of emphasis I hope my remarks will fit in with the definition of mariculture as set out in the report of the ICES Working Group on Mariculture, viz:

... the managed production for commerce or recreation of marine organisms involving intensive and comprehensive husbandry of plants or animals in a marine environment wherein population densities may be much greater than in the wild. In such ventures, private ownership or tenure with legal control and protection is possible and individual organisms may either be set free to grow in a natural environment (restocking operation) or grown to marketable size in a controlled environment (farming operation).

Restocking

One of the oldest ideas in fisheries biology is the notion that year-class abundance is determined by natural mortality in early life history stages. As the decades have gone by, it has become increasingly clear that for many species there are substantial differences in larval and juvenile survival from year to year which reflect variations in natural conditions.

Meanwhile, those who lack the patience to wait until the basic research is undertaken have long since decided that at least some of the uncertainty can be lessened by cultivating the desired organisms to a stage that gets them past the danger period and then setting them free.

There is a long history of trial and error associated with these schemes for large-scale production of juveniles. For North America, much of the history was reviewed in 1970 in the North American Fisheries Society volume, *A Century of Fisheries in North America*, and more recently by Parker (1989). The emphasis was at first on freshwater and anadromous species, no doubt because they were readily at hand and it was easier to control the environment for rearing. Shortly after the turn of the century, and in tune with the optimistic tenor of the times, there were substantial programmes of government-sponsored activities aimed at both freshwater and marine species. In the United States in 1940, 98% of the eggs and 75% of the fry produced were of marine species; Atlantic cod (*Gadus morhua*), flounders of various species, and pollock (*Pollachius virens*) (Parker, 1989).

Much of this activity shranked in North America. The results were either disappointing or not measurable and for a period in mid-century many of the efforts devoted to the rearing and releasing of juveniles went into a period of decline. But for salmon, particularly Pacific salmon (*Oncorhynchus* spp.), the pressures of dam construction, coupled with the development of better understanding and new technologies, led to a rekindled enthusiasm for "ocean ranching", or "restocking" (Larkin, 1974).

Since that time, artificially enhanced production has played an increasingly important role in the maintenance and increase of abundance of salmon. For example, almost 20% of the present catch of Pacific salmon in British Columbia originates from some sort of enhancement activity (Fisheries and Oceans Canada, 1987)1. The production from hatcheries in central Alaska contributes perhaps a third of the total catch of pink salmon (*O. gorbuscha*) of the region. The recent oil spill at Valdez, Alaska, was close to the heart of this operation.

Perhaps the greatest success story of "ocean ranching" is the Japanese practice with chum salmon (*O. keta*), which in recent years has produced an annual catch in the order of 75 000 t. Several countries, notably Iceland and Sweden, have achieved considerable success in the ranching of Atlantic salmon released as smolts, but current enthusiasm seem to be focused more on farming operations.

The culture of other marine species in Europe has a long history that is intertwined with local transplantation activities. In 1904, Schmidt saw possibilities for transplanting young eels into river systems they might otherwise not reach (Schmidt, 1906). Subsequently, both before and after World War I, large numbers of elvers

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1 The techniques of salmonid enhancement vary among species and in the degree of intervention in natural processes of production. Some, such as lake fertilization and the construction of artificial spawning channels, do not perhaps technically qualify as devices of "restocking". In the cultural practices that do qualify, the major differences lie in the length of time the various species are held before release. At least, they are held until the eyed egg stage, when they may then be planted loose in stream gravel or in small containers (a method pioneered by Vibert). More commonly they are held until emergence (pink salmon, *O. gorbuscha*) or for a full year or more until they become smolts (Atlantic salmon, *Salmo salar*, coho salmon, *O. kisutch*, and rarely in recent decades, sockeye salmon, *O. nerka*).
were transplanted from England to Germany (Thomason, 1981). Fishermen of Jutland made the earliest recorded transplant of plaice (*Pleuronectes platessa*) in 1892. Garstang (1905) was a strong proponent of transplanting and since then a large number of transplantation experiments have been conducted (Graham, 1956). In the early years of the century, plaice were also being reared in hatcheries in Norway (Bardach et al., 1972). Various species of flatfish have been reared by the White Fish Authority in the United Kingdom (Kirk, 1985). Cod (*Gadus morhua*) have been reared and released from Norwegian hatcheries for a century (Bardach et al., 1972).

The success of these various attempts at sea ranching has not been altogether clear. The benefits of transplant apparently exceed the costs, in some cases by as much as 2 to 1 (Wimpenny, 1953), but hatchery practices, when "tame" young fish are released into the natural environment, are not as readily justified.

If either the hatchery products or the transplants are released in waters that fall under national jurisdiction and remain therein until commercially harvested, there are also the questions: Do the hatchery fish replace natural production? and, Do those who pay the hatchery costs obtain the benefits? And if, as is more likely, the hatchery fish (or transplants) do not remain in the zone of national jurisdiction, does the country that provides the costs get the benefits? Within a country, the same questions apply with respect to private ownership: if a company releases young fish, how can it be confident that it will reap the benefit? These considerations of ownership, coupled with the increasing scarcity and cost of catching naturally produced fish, have helped to make fish farming an economically attractive alternative to restocking or ocean ranching.

More generally, as one of the referees of this paper has pointed out, restocking programmes must meet four conditions for success:

1. ability to produce or collect fry or spat of good quality;
2. sufficient understanding of the mechanisms of recruitment to know when, where, and under what circumstances releases will actually enhance recruitment;
3. availability of the enhanced stock for capture; and
4. the existence of adequate use rights to protect investments.

If these conditions are not met, then for one reason or another programmes will falter and fail.

Farming

Armed with the experience of past failures and successes, and supported by the expertise of a wide range of contemporary specialists, large-scale farming of aquatic organisms is now going through an explosive period of growth. It is to be expected that there will be many unpleasant surprises for those who invest in the business. Supply will periodically exceed demand, as is the case for farming of pigs, cattle, and chickens. The recent glut of farmed salmon is a good example. For fish farming, the costs of feed are critical to business success and currently hinge on the availability of meal from processing of fish from wild stocks. Indeed, fish farming can be seen as a device for using production at one trophic level for controlled production at a similar or different trophic level. Smaller operations will frequently underestimate the necessary level of investment. Nearshore locations, convenient for the logistics of taking materials in and product out, may be vulnerable to algal blooms, pollution, and predators of various kinds. Concentration of operations in good locations increases the risks of disease. Labour costs may also be a major determinant of economic success. For these several reasons, the highest priced seafood products are the most attractive for farming, especially if the market is relatively far removed from the site of production.

Some of these problems have long since been familiar to those engaged in the shallow seas farming of mussels, oysters, scallops, abalones, prawns, and seaweeds especially in Asia. A large literature has been devoted to the technologies of their culture (e.g. Imai, 1977). In North America, large-scale mariculture has been slow to develop, in part because of the lack of an infrastructure of expertise, but in larger part because of the web of economic, social, and political factors which have not been conducive to aquaculture as a business (Anon., 1978).

Wherever it occurs, mariculture poses problems for coastal zone management. If it is too intensive, it generates its own problems of pollution and vulnerability to epidemics. If it is too dispersed, it is less economic and pre-empts other uses of the coastal zone.

The culture of bivalves is a major economic enterprise in many parts of the world and poses some particular problems because of the substantial dependence on naturally produced food organisms. I am not aware of the extent to which cultured bivalves may influence local ecosystem dynamics, but it seems likely that such effects exist. Cultured bivalves may concentrate paralytic toxins from dinoflagellates with disastrous effects. They may also be vehicles for transmission of human bacteria and viruses. Fortunately, these are well-known dangers. Preventative measures, such as seasonal and area closures, and depuration techniques, provide adequate public protection in modern commercial operations.

Until quite recently, the farming of aquatic organisms was dominated by a few groups of species that were highly valued for food and readily manipulated (salmonids, carp, catfish, tilapias, mullets, milkfish, bivalve molluscs, shrimps and prawns, and seaweeds).
The list of species and countries involved shows every indication of growing rapidly. For example, recent issues of the trade magazine, *Fish Farming International*, have mentioned commercial initiatives on mahi mahi (*Coryphaena* sp.) in Australia, striped bass (*Morone saxatilis*) in the United States, sturgeon (*Aci-
penscher baeri*) in France, sea bass (*Dicentrarchus labrax*) in Greece and France, eels (*Anguilla anguilla*) in Den-
mark, West Germany, Sweden, and Italy, Australian freshwater crayfish or marron (*Cherax tenuimanus*) in
Australia, giant clams (*Tridacna derasa*) in Palau, turbot (*Scophthalmus maximus*) in Spain, and Atlantic salmon
(*Salmo salar*) in Tasmania.

The foregoing are only a few examples from hundreds that are probably in various stages of commercialization,
ranking from idle speculation through to experiment, demonstration, substantial investment and, in some
cases, bankruptcy.

At the same time, there are major new scientific discoveries and technological developments that give
great promise for aquaculture. In addition to the sub-
stantial applied literature on nutrition and food con-
version, and the increasing experience with induced
reproduction and manipulation of the sex of young fish,
there are major new prospects for the use of recom-
binant DNA and monoclonal antibody techniques for
disease diagnostic kits and vaccines. Genetic selection
will continue to be used to develop strains with suitable
characteristics for culture. Just over the horizon there
is a Pandora’s box of genetic engineering tools that will
be used to create new varieties of fish for farming.
Perhaps one of the most significant current dev-
velopments is the engineering of enclosures for offshore
fish farming which may resolve many of the problems
of pollution and competition for good sites in nearshore
fish farming. With largely automated production, they
may also reduce labour costs. As is often the case in any
burgeoning new enterprise, the professional literature is
currently running well behind the pace of events. It will
be a decade or more before much of the current activity
will be adequately consolidated into manuals for prac-
tice and textbooks for young students.

**Recruitment**

The harvesting of wild stocks, programmes for re-
stocking, and the operation of fish farms share a major
concern: how to ensure a supply of new recruits. For
the manager of fisheries on wild stocks concern is
expressed in the long-standing emphasis on research
into the factors that determine recruitment. In more
general terms, this research is directed to the core
problem of population dynamics: what determines the
abundance and distribution of animals. It is now widely
recognized that physical and chemical factors of the
environment set the stage on which biological factors
operate, but which of the two sets of factors is con-
sidered to regulate abundance has long been a source
of controversy (Larkin, 1989). If one has faith in den-
sity-dependent mechanisms, then stock/recruitment
relations are of prime interest. The ICES Aarhus sym-
posium was a comprehensive summary of that approach
(Parrish, 1973). If, on the other hand, one has more
faith in density independent mechanisms, attention is
focused on oceanographic circumstances. The Lisbon
ICES symposium gives an excellent perspective (Par-
sons *et al.*, 1978). Whatever one’s faith, interest usually
centres on early life history stages, for it seems to be
then that the mortalities occur which are decisive in
determining year-class size.

The common set of four questions that usually remain
unanswered was succinctly summarized by Incze
*et al.* (1986) in their study of king crab (*Paralithoides cam-
tschatica*):

What factors [are] most influential in determining patterns
of year class size . . .; do the same principal factors tend
to limit year-class recruitment in most years; do these
same factors predominate regardless of the level of the
stock, and, are certain definable periods in life history most
often involved in the recruitment-determining processes?

These questions have proven to be very difficult to
answer, and the answers are probably not the same for
various species. To quote from the 1980 IOC workshop
on larval pelagic fishes, “Success in defining such
relationships has been sporadic and fleeting. And
relationships which seem to hold for one species fail
even closely related species in seemingly similar
environments . . .” (Sharp, 1980). A recent comment-
ary by Sissenwine (1989) summarizes the extensive
studies of recruitment processes on Georges Bank and
illustrates the complexities of both the physical setting
and the interactions among the many species of fishes
(and other organisms). The mechanics of intraspecific
competition among individuals of the same cohort are
a particularly important area for study.

For the practitioner of restocking, the problem of
recruitment is only less worrying if the fish are past a
critical stage of early life history (if there is one), if
the restocked fish survive as well as wild fish of
comparable age and/or size and, if the sum of the
wild plus the restocked fish does not precipitate some
compensatory mortality or decrease in growth rate. The
usual preconception is that the longer the time young
fish are reared before release, the more will survive,
but life is never so simple.

For Pacific salmon, for example, release is usually
timed to coincide with the natural age of entry into salt
water, thus ensuring adjustment to estuarial and open
ocean salinity and eventual return to the stream of
origin, which is usually the site of release. It may be
that restocking of many purely marine species may also
require consideration of the precise time and place of
release if the restocked fish are to follow the same paths of migration as their wild counterparts. There are many opportunities for experimentation in this regard and it is to be hoped they will be pursued to the advantage of both the hunters and ranchers of fish.

The fish farmer may derive his "seed" from domesticated brood stock or by collecting mature wild fish, their eggs, or their juveniles, the last option being the converse of restocking. (The ICES Working Group on Mariculture did not have a word for this practice and neither "stocking" nor "restocking" seem appropriate.) The genetic implications of the use of cultured brood stock are obvious and should be seen not only as an opportunity for more successful fish farming, but as a means of gaining greater insight into the genetic diversity of wild stocks.

The question of whether in fish farming to collect wild larvae, underyearlings, or pre-recruits to a commercial fishery, is somewhat akin to the the cattleman's decision whether to buy calves or heifers, or to operate a feedlot for "finishing" stock before they go to market. The decision, as in all business, is a trade-off between risk and potential profit. It is interesting to speculate that the mariculture industry will soon mature into those kinds of considerations (if it has not already done so).

Fundamental to all the uncertainties of recruitment is the question, what limits total production of fish in the ocean? Enhancement of the abundance of one species may well depress the abundance of others. Primary productivity and the efficiencies of conversion to higher trophic levels may set limits on the combined total production of wild and cultured stocks both on a local and regional basis. If so, one of the ecological implications of large-scale intensive mariculture may be a decrease in wild production of seafoods.

Extensions of range

Among the more dramatic manoeuvres of fish culture are the attempts to establish aquatic organisms in environments far away from their natural geographic range. Salmonids, for example, have been introduced throughout the temperate zones of the world and, at higher elevations, even into tropical regions. Various carps and tilapias have also been introduced wherever it has been perceived they might flourish. The list of transplants and introductions into European freshwaters is very lengthy (Rosenthal, 1978).

Attempts to transplant organisms from one ocean to another have on occasion had at least temporary success. For example, Pacific salmon from the west coast of North America have been introduced to the Atlantic coast of North America, and Pacific salmon from the Pacific coast of the USSR have been introduced to the Atlantic coast of the USSR. Pacific salmon have been established in New Zealand for half a century, and currently seem likely to become established in Chile.

King crab have been transplanted from the Sea of Okhotsk to the Barents Sea (Orlov and Ivanov, 1978). Various attempts have been made to introduce Atlantic lobsters (Homarus americanus) to the Pacific coast of North America. The Japanese oyster (Crassostrea gigas) has been widely distributed in the northern hemisphere. There are many more examples that serve to illustrate that long distance extensions of range have long been and will no doubt continue to be one of the blunt instruments of fish culture. With the growth of large-scale fish-farming enterprises, it is to be expected that there will be many inadvertent introductions. On the Pacific coast of Canada, for example, Atlantic salmon (Salmo salar) that have escaped from fish farms have been reported by fishermen.

Concern has been widespread that transplants and escapes from fish farms may "genetically pollute" natural stocks. To what extent this concern is justified has not been adequately explored. The STOCS symposium (Billingsley, 1981) was a significant contribution in emphasizing the importance of adaptation to local conditions. Since that time there has been a large amount of research on adaptations of local populations of fishes, particularly salmonids; several reviews are currently in progress. Meanwhile, escapes are contributing substantially to spawning populations of Atlantic salmon in Norway. And although it is almost the universal practice not to transplant Pacific salmon from one stream to another, there remains the concern that the selection involved in the techniques of collecting eggs and of rearing the young may adversely influence the genetic makeup of stocks that are ostensibly being "enhanced" by increasing their abundance.

Future prospects and the implications for research

Predicting the future in any field of human activity is generally a precarious business. Fisheries is no exception. For example, just 25 years ago, the New Scientist ran a series of articles on "likely developments of the next 20 years"; they were published as "The World in 1984". Sir Alastair Hardy predicted there would be "factories spread along the coasts" of the United Kingdom raising so many young flatfish using Shelbourne's techniques as to cause overcrowding and "stultifying growth". In consequence, Garstang's proposals for transplants would be resurrected! Hardy also predicted large-scale midwater trawling for red fish (Sebastes marinus), which proved to be so, and for lantern fish (myctophids) which proved not to be so, and for krill in the Antarctic, which Hardy believed might be "making the greatest addition to man's food supply of the century", but which does not look to be so now that it has been tried.

In the same volume, among other things, Roger Revelle predicted control over the genesis of hurricanes
by using magnesium oxide cheaply produced as a by-product of using nuclear power to convert salt water to fresh (which at the same time warmed the ocean beaches nearby). Children would ride on porpoises that had been trained with Indian music. A worldwide network of satellites, deep-anchored ocean buoys, and meteorological stations would enable accurate long-range weather forecasting. World climate would warm.

From time to time in recent years I have been asked to look into the future, the inference being that the older you get the more chance there is that you will agree to do so because the less chance there is that you will live to be embarrassed. But things move very quickly nowadays and it is not uncommon to find that what one predicts has already happened. Nevertheless, because I was asked to venture a few futuristic comments and to indicate their implications for research, I will be a good sport and do so.

The first prediction I would venture is that the world harvest of wild stocks will not increase and world mariculture production will exceed the harvest of wild stocks before the year 2020. The demand for protein seems certain to be sustained, the only real question being whether mariculture will produce protein at a price that will be competitive. The increasing use of automation in larger scale operations, better control over nutrition and disease, genetic improvements, and the assurance of a quality product over a progressively longer season, will all serve to make farmed seafoods competitive with wild stock and with other protein foods. A great deal of applied research and trial and error experience will be quickly communicated around the world. The basic research of greatest significance to advances in fish farming will be in the field of genetics as the genetic engineers become increasingly adept at splicing desirable traits into domesticated stock. The old jokes about crosses between this and that will become a reality.

The second prediction is that, for fish farming and restocking of many species, the greatest problem will be maintaining the supply of eggs or early life history stages. This will mean increasing interest in natural recruitment processes and, perhaps, at long last, closer working relationships between oceanographers and fisheries researchers. Restocking may be uneconomic or even futile unless the releases are of the optimum size and age, at the optimum time and place, and use the most appropriate techniques. Farming will often be able to draw on brood stocks, but until that technology is perfected for a species there will be continued reliance on wild sources of mature adults or of juveniles.

My third prediction is that seafood farming will move progressively seaward, primarily to avoid the competition for sites and pollution near shore, but also perhaps to take advantage of some natural sources of food, particularly for young fish.

A fourth prediction is that there will be much experimentation with "polyculture", the raising of several seafood crops together. Freshwater aquaculture has a large literature of empirical knowledge concerning which species combinations are most effective, but the implications for the theory of community structure and ecosystem dynamics have not been adequately explored. Much the same may be said of brackish water and marine polyculture. It seems likely that experiments with various mixes of species of fish, invertebrates, and seaweeds will be used both to fine tune the economics of farming and to gain better understanding of the underlying mechanisms of efficient ecosystem functioning. Imagine a farm that produced oysters and seaweeds above, shrimps, giant clams, and abalones below and mullet in the middle, and you have the challenge. It even becomes useful to consider the interactions between natural and maricultural ecosystems on various scales of time and space.

All of these developments will strengthen the commonality of interest of researchers in fisheries and mariculture. There has been a tendency for the two groups to be somewhat separate from each other, a tendency that is heightenened if they are under different administrative jurisdictions (for instance, if fisheries is lumped with, say, oceans in one department, and aquaculture is lumped with agriculture in another department). Because the product of both kinds of enterprise serves the same end markets and relies on a common body of knowledge and knowhow, it will make sense to ensure that it is administered in a coordinated, if not an integrated, fashion. I believe this will come to pass.

I believe also that we will fight a common cause against the increasing threats of pollution. As the wastes of contemporary society accumulate, there is a greater and greater temptation to dump them at sea - preferably far out to sea. The farther out of sight, the farther out of mind. As the traffic in the transport of oil inevitably increases, so do the risks of oil spills for which the technology of containment is hopelessly inadequate. Traffic in highly toxic materials is greater now than ever before. Many rivers continue to act as conduits for the transport of a witch's brew of wastes through critical estuarial areas to the sea. The occurrence of cancerous skin lesions on fish in confined bays and estuaries is now commonplace (Stich and Acton, 1976; Stich et al., 1976; Dunn and Stich, 1976; Stich et al., 1977). Each of us can readily cite dozens of examples of pollution of one kind or another from our own experience. The growth of mariculture with its substantial public and private investment will surely strengthen the cause of fisheries managers in their long-standing war of attrition against pollution.

Economists and sociologists should also find the next two decades full of opportunities for research. In addition to incorrectly predicting what will happen next, they will have the pleasures of considering the optimum allocation of coastal zone resources among the various user groups, the economic competition and symbiosis
of mariculture and fisheries on wild stocks, and the devices by which governments may manipulate both for social and economic effectiveness and to achieve re-election.

Finally, it seems likely that circumstances will force researchers to look at mariculture in multidisciplinary ways with systems perspectives. At the level of the individual fish farmer or the commercial firm, it is necessary to have a well-developed infrastructure for access to seed stock, food, equipment servicing, veterinary services, and, most important, profitable markets. Whatever works to make the enterprise pay is what will evolve as the best technique. At the level of government, it is necessary to have in place a set of policies and programmes that regulate the industry in the best public interest, for which there are many social and economic dimensions. There will be a need for teams of researchers to address the various issues involved in such complex systems. It may well prove that the biological factors involved in different kinds of mariculture combined with the inherent variability in social and economic circumstances will inevitably drive the evolution of mariculture into a wide diversity of kinds of operations.

One way and another I can foresee a close and effective coordination of fisheries and mariculture interests in research, and in the protection and management of aquatic resources. Who knows, it may even be responsible for a change in the name of this august body from the International Council for the Exploration of the Sea, to the International Council for the Exploration, Protection, and Development of the Sea.

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