

The ocean's yield of seafood depends on international cooperation. An integrated management system for salmon could be a beginning.

Toward a Planetary Aquaculture—the Seas as Range and Cropland

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THE OCEANS SEEN FROM SPACE

Views of the earth from orbiting satellites are changing our perception of this planet (Fig. 1). Images relayed by satellites show that the distribution of heat at the earth's surface is uneven, the result of dynamic processes. Heat transfer in the sea occurs by the slow, stately circulation of ocean currents; in the air heat is transferred by the wind. Heat transfer processes in the ocean and on the land produce the phenomena we call climate. These processes also affect the distributions of fresh water, soil, and vegetation on land and of salinity, nutrients, and marine life at sea.

To the observer from space, the earth appears as a microcosm, a fit subject for a garden. To live up to the responsibilities that go along with this expanded perception of our world, we must become planetary gardeners. For of all the skills developed in the course of our cultural evolution, none is more basic to our survival than gardening. The skill of the gardener lies in his knowledge of the kinds of plants and animals that will grow well on his particular plot and how to select the ones that will produce high yields for the least cost in energy and materials.

Among the many benefits to be derived from good gardening practice, not the least is beauty. Well designed and managed flower gardens, farms, and forests are among the most beautiful features of our planet. It is no accident that when and wherever civilizations have arisen, parks and gardens have been among the most widely appreciated forms of aesthetic endeavor.

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gardens of tropical fish hobbyists. No matter what the medium and the scale of the gardening, the same basic principles apply—the appropriate selection and location of crops and the conservation of energy and materials. If we regard the whole earth as a garden plot, we cannot ignore the seas in our development of a planetary garden design. We must learn to regard them in the agricultural sense as range and cropland to be carefully and lovingly husbanded rather than as a limitless source of freebooty.

Continuation of the nationally self-serving and often shortsighted methods now being used to exploit the world's fisheries will most certainly insure that the sea will never reach its potential as a reservoir of protein—protein sorely needed in a world increasingly beset with malnutrition and food shortages. What we most desperately need to do is to develop a rational system of planetary aquaculture through which we can

From bottle gardens to national parks, most of our garden designs have focused on dry land. Some notable exceptions, however, are the swamp gardens of the Aztecs, which provided immense yields of food crops; other examples are flower gardens in the mangrove swamps of South Carolina and Georgia, underwater gardens and parks in Florida and the Caribbean Islands and, on a smaller scale, the aquarium



Figure 1.—The earth from space (NASA photograph).

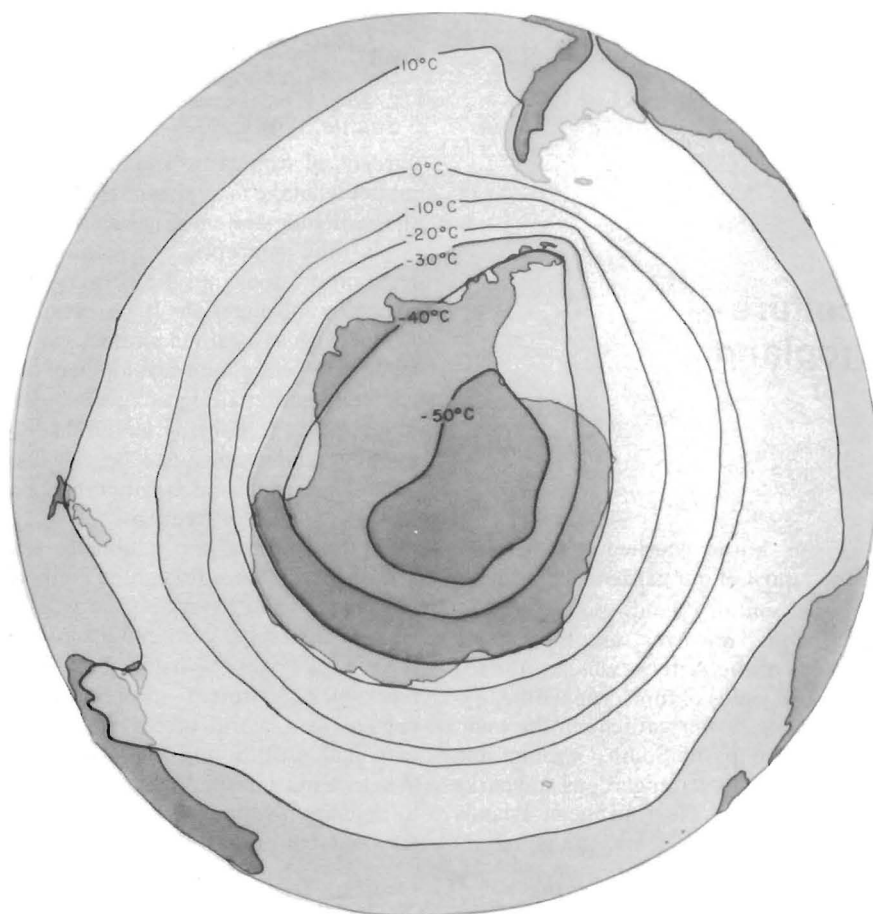


Figure 2.—Surface air temperatures—southern hemisphere, winter.

apply good, sound gardening sense and knowledge of the basic physical geography of our planet to the husbandry of our ocean resources.

The most heavily exploited parts of the world's oceans, the seas of the polar and subpolar regions, have suffered the most from destruction of valuable stocks of fish and marine mammals. What basic factors should we integrate with our good gardening sense to determine how we ought to be farming these cold seas? What crops will be best? How can we cultivate and harvest them with the lowest energy cost and the least damage to the environment?

COMPARISON OF THE POLAR HEMISPHERES

Because of the uneven distribution of land and water, the earth's hemispheres are distinctly different when viewed from points of vantage in space above the polar regions.

Viewed from above the Antarctic, the Southern Ocean surrounds the ice-

capped land mass in a nearly unbroken girdle. Only the tip of South America and a few minor islands penetrate the ocean south of lat. 50°S. As far north as lat. 40°S, Tasmania and the South Island of New Zealand are the only other significant land masses. In subantarctic regions, winds and ocean currents exhibit the simple patterns produced by the earth's rotation and latitudinal differences in solar heating (Fig. 2). They are little modified by irregularities in the earth's solid surface. The climate reflects the prevailing westward flow of wind and water and the nearly direct correspondence of temperature and latitude.

Quite a different view is presented to an observer above the Arctic regions. Land masses predominate, particularly in the sector between long. 120°W and 140°E. Differences in the absorption and radiation of heat by land and water and the deflection of winds by mountains and of ocean currents by bordering lands, all tend to complicate the patterns of weather and climate. In the Northern Hemisphere, these patterns

are twisted, stretched, and compressed in contrast to the smooth, concentric patterns of the Southern Hemisphere (Fig. 3).

DETERMINANTS OF PRODUCTIVITY

Organic production both on land and at sea depends on the same sources of energy and matter: light and heat, water, air, chemical nutrients, and seed. However, land and sea differ in the relative proportions of air, water, and solid earth interacting at their surfaces. On land, the solid earth and air are in contact everywhere and water is unevenly dispersed. At the sea surface, the principal interface is between air and water, and solids are unevenly dispersed. Fertility depends largely on the distribution of the dispersed phases. On land, it is highest in well-watered soils in river valleys and on old lake bottoms. Seawaters are most fertile wherever suspended and dissolved solids are concentrated near the surface by the action of currents. In both cases, nutrient chemicals derived from land are distributed by moving water to fertile areas where they become available to green plants. These, using the radiant energy of the sun, produce the organic matter upon which all life on earth ultimately depends. For organic production to occur, however, seed must be available, appropriately matched to local conditions. Without it, even the most fertile area cannot produce the balance of organisms needed equally by natural ecosystems and well designed gardens.

RANGE AND CROPLAND

Classifying marine environments in basic agricultural terms would seem an appropriate early step toward the development of a rational system of planetary aquaculture. In agricultural terminology, the oceans would be comparable to open range. Coastal waters and continental seas are generally subject to the jurisdiction of the bordering nations and are more amenable to intensive resource management. They can be reasonably likened to cropland. Public ownership on the high seas, however, would represent global interests rather than the national ones that prevail in most land areas with the exception of Antarctica. Private interests in coastal waters would properly encompass those of nations and states as well as of

corporations and individuals. In basic agricultural terms, then, the seas of the world would be classed either as ocean ranges or coastal croplands.

MANAGEMENT

Ocean ranges might be recognized as global common property with management responsibility vested in an international regulatory body. The right to exploit the resources of the ocean ranges could then be leased to responsible applicants such as publicly-owned range land in the United States is leased to livestock growers. Appropriate charges could be assessed against the lessees. The proceeds could then be used to sustain management programs designed to protect and enhance the productivity of the ocean ranges, and to insure distribution of their benefits to best serve the interests of the global public.

Coastal croplands could be managed by the coastal states according to their special customs and interests. If their management practices could be shown to benefit stocks that are harvested on the high seas, responsible coastal states could be credited for appropriate shares of the value of the high seas harvest that would be proportional to their contribution.

For migratory stocks, such as salmon, that return from the ocean range to coastal rivers, the coastal states should have the exclusive right to harvest. To support international management of the high seas, however, they might be charged a portion of the value of the catch for use of the ocean range where their salmon fatten and grow to maturity. It does not make good sense to expend precious supplies of energy by sending boats out to net salmon at sea. Given the opportunity, salmon will return to their native rivers to spawn. There they may easily be caught in traps where they can be kept alive. With this kind of harvest, it would be relatively simple to keep appropriate inventories of fish returning to each coastal stream and to release enough to insure sufficient seed for the next generation. Caught from boats fishing out at sea with gillnets, salmon are generally dead or severely injured when brought aboard. Harvested in this manner, it is seldom possible to determine in what stream they would have spawned and impractical to release part of the catch unharmed to insure sufficient produc-

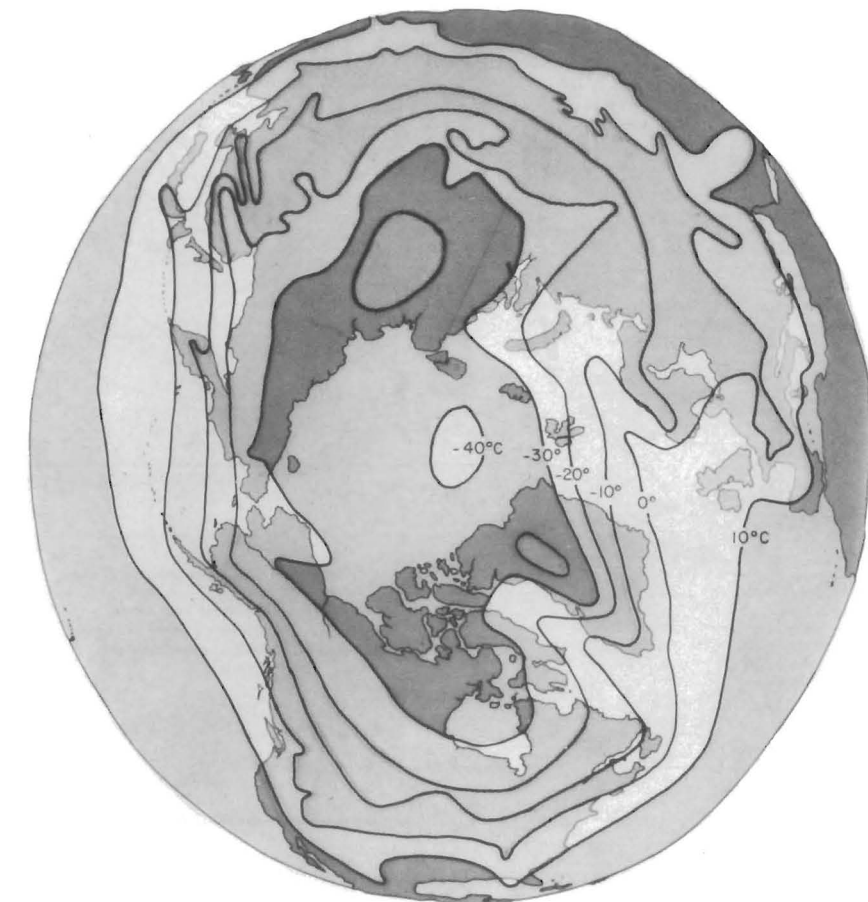


Figure 3.—Surface air temperatures—northern hemisphere, winter.

tion of seed. Management of such a fishery is difficult and its results inherently uncertain. Shore fisheries using traps managed by the coastal states and not subjected to high seas net fishing would provide a much more efficient way to sustain a maximum harvest of salmon.

CHOOSING THE CROPS

The development of agriculture has spanned thousands of years. Nevertheless, the species cultivated as major crops are few relative to the number of wild species that have survived to the present day. Goats, sheep, pigs, and cows were domesticated in that order and became our basic livestock. Chickens, ducks, geese, and turkeys became the basic domestic fowl. Wheat, barley, corn, and rice became the staple grains of tropical and temperature regions. Oats, rye, and millet were better adapted to colder regions. There is no reason to believe that the cultivation of sea crops will not also be restricted to a

relatively few, easily managed, readily transplanted species.

Salmon, of all marine species, seem to offer the best prospects for early development of an aquacultural system capable of taking advantage of the natural productivity of ocean ranges. The reasons for this are:

1. The vulnerable, early stages of development are spent in fresh water. Relative to the open sea, this environment is both accessible to and can be protected by man.
2. There is already available a considerable body of knowledge about the life history of salmon and a proven hatchery and nursery technology that can be applied to a rational system of management.
3. After they migrate to sea, the far-ranging salmon can efficiently seek out productive feeding grounds.

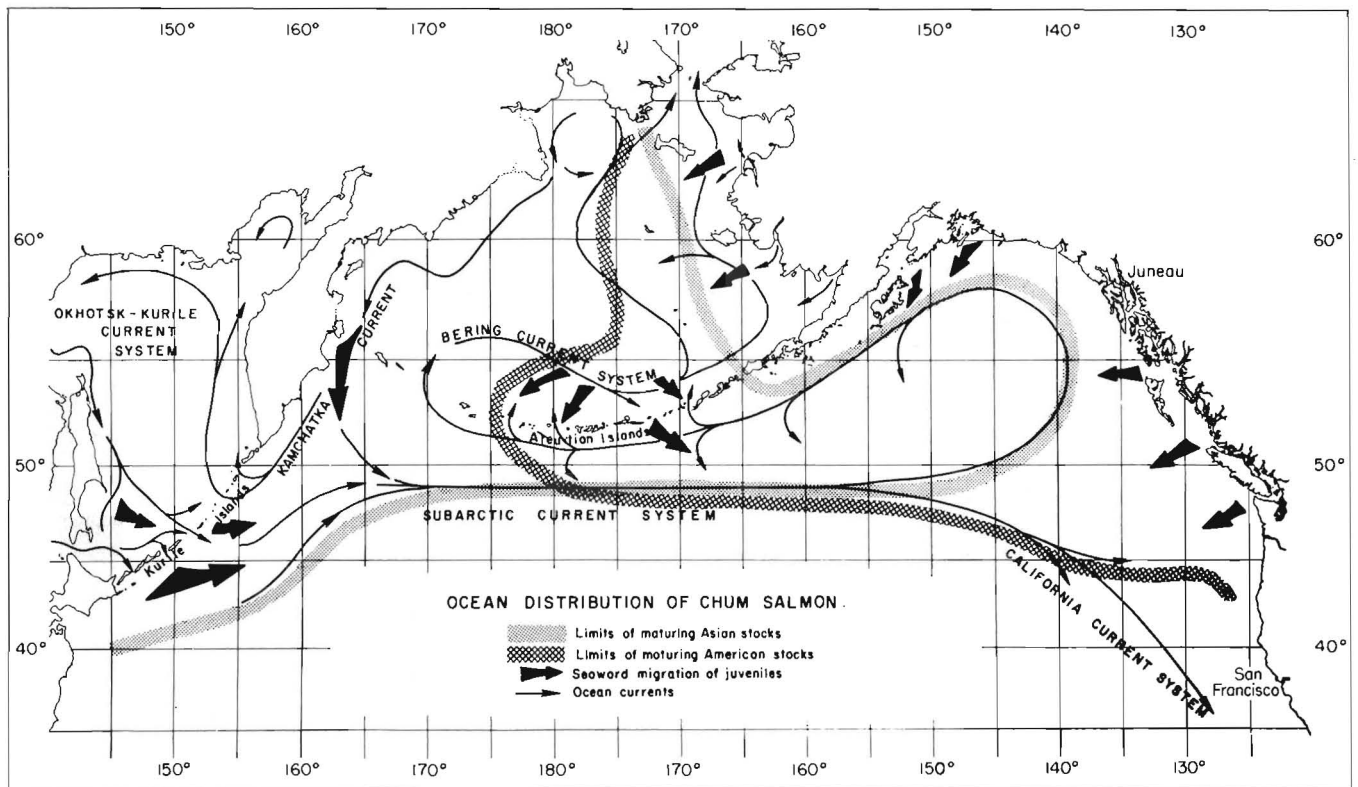


Figure 4.—Ocean distribution of chum salmon.

4. After fattening for several years at sea, salmon return to their native rivers without having to be herded. There they may be easily harvested with traps at a very low energy cost.
5. The fecundity of salmon is high—a single pair will produce thousands of offspring—and the rate of growth is rapid.

Given these characteristics, it would seem prudent to phase out offshore gillnet fishing in favor of catching salmon as they enter their home streams to spawn. Using live traps wherever feasible, this would provide not only a simple, efficient, easy-to-regulate way to harvest but, combined with artificial propagation to mitigate the loss of spawning areas, could also become a powerful tool for rebuilding depleted stocks. Admittedly, this would be at the expense of the high seas gillnet fishery, but it would serve better the interests of the consuming public by making possible the rational management of one of its major fishery resources. The salmon resource has proved vulnerable both to degradation of spawning areas in the coastal rivers and to the effects of high

seas gillnet fishing. Indeed, when Atlantic salmon stocks, already so seriously depleted by the effects of urban and industrial development that they had disappeared from most of the major rivers of western Europe and the northeastern United States, were subjected to intense offshore fishing in Greenland waters in the 1960's, it appeared that many of the remaining stocks were being threatened with extinction. Fortunately, in 1972, the International Commission for the North Atlantic Fisheries (ICNAF) approved an agreement that was subsequently ratified by the Danish parliament to phase out the Greenland offshore salmon fishery. Great Britain, the United States, and Canada have banned, and Ireland has restricted, offshore net fishing for salmon to their fishermen. Norway still permits an offshore fishery in the Norwegian Sea.

Although the Pacific salmon have not yet been as severely depleted as the Atlantic species, the combination of freshwater habitat destruction and intensive high seas fishing have taken their toll. The total catch of all species by all nations, which peaked during 1934-43 at an average of 712,000 metric

tons annually, declined by one-third to an average of 478,000 metric tons for 1960-71.

The native fishing peoples around the rim of the Pacific Ocean, from Northern Japan to California, who were regarded as primitive by the invading bearers of civilization, generally entertained a deep reverence for salmon and had fished for them with weirs and traps for thousands of years. Sensible harvesting customs, built into the very fabric of their cultures, recognized the value of restraint in the capture of this precious resource. By learning to use the wisdom and restraint employed by these ancient cultures in harvesting, and by thoughtful application of appropriate modern technology to salmon husbandry, it should be possible to restore and eventually even to exceed the abundance that once characterized the resource.

With the many conflicting national interests of maritime states, an effective international management system for the exploitation of the living resources of the high seas will have to be developed. Our ability to sustain and distribute fairly the ocean's yield of sea food to the world's markets will depend largely on agreement between nations

on the extent of national jurisdictions and access to common property resources at sea.

Taking one step at a time, it would seem that establishing an integrated management system for the salmon fisheries could serve as a reasonable first step toward general international management of ocean resources and as an early model for the development of a planetary aquaculture.

There are already in force multinational agreements for the protection of both Atlantic and Pacific salmon, instituted primarily at the insistence of the coastal states that are making serious efforts at conserving and rebuilding their native stocks. In 1952, a treaty was negotiated between Canada, Japan, and the United States that required Japan to abstain from fishing for salmon east of long. 175°W. Canada and the United States do not permit their fishermen to take salmon on the high seas. In 1956, Japan and the USSR negotiated a convention that prohibits Japan from salmon fishing along the Kurile-Kamchatka coasts and in the Sea of Okhotsk; it also subjects Japanese fishermen to annually determined quotas west of the abstention line at long. 175°W. The ICNAF Convention of 1972 has undertaken to phase out the Greenland fishery for Atlantic salmon. These multinational agreements indicate a trend toward the elimination of high seas net fishing for salmon. If high seas fishing nations lacking sufficient coastal access to the salmon resources could be assured of reasonable commercial access to the salmon markets, complete phaseout of salmon fishing on the high seas could become a realistic objective of international ocean resource management.

STOCKING THE OCEAN RANGE

Assuming that international regulations ultimately will be able to protect salmon from high seas net fishing, we must consider how to stock the ocean ranges to insure optimum yields. Wherever possible, pollution abatement and restoration of natural spawning areas will have to play a continuing role in building back the depleted stocks. Where this is not possible and the streams and rivers where salmon once spawned have been irreversibly

changed, hatcheries can be built to restore some of the lost capacity to produce salmon. Although hatchery production cannot reasonably be expected to match that of extensive natural spawning, the survival of eggs and fry in efficient, well located hatcheries and nurseries often greatly exceeds that of natural systems. Development of fishways to make areas of streams hitherto unavailable for spawning accessible to salmon and the seeding of virgin areas can also be used to stock the ocean ranges.

Islands such as the Aleutians and the Kuriles in the Pacific and Iceland in the Atlantic, that lie athwart the routes that salmon travel on their way to their feeding grounds, are strategically located for injecting salmon into the ocean ranges (Fig. 4). Being volcanic, these islands are potential sources of geothermal energy that could provide heat and power for operating efficient, temperature-controlled fish rearing facilities. From these island bases, selected stocks of salmon could be released where currents would carry them quickly to the ocean feeding grounds. By using temperature to control the rate of development while the salmon were being reared in fresh water, it would be possible to stagger the releases of the cultured stocks so that the harvest of returning adults would be spread over a convenient period.

SEEDING THE SOUTHERN OCEAN WITH SALMON

Bounded on the north by the Subtropical Convergence near lat. 40°S, and on the south by the ice-covered mass of Antarctica, strong westerly winds drive the waters of the Southern Ocean continuously eastward in a current known as the West Wind Drift. These waters provide an environment that should be favorable for the oceanic part of the life cycle of salmon. Water moving upward from intermediate depths inside the Antarctic Convergence brings to the surface nutrients dissolved from decaying marine organisms and from glacial flour dropped by melting ice. These currents are carried northward to the region of the Convergence (generally between lat. 50° and 55°S) by cold surface waters flowing outward from Antarctica. Small, shrimplike crustaceans, called krill, that would be excellent

feed for salmon abound inside the Antarctic Convergence. Particularly dense concentrations are found in the Scotia Sea to the southeast of Tierra del Fuego.

Just inside the Antarctic Convergence where dense concentrations of krill begin to appear, the range of water temperatures is from about 5° to about 2°C. Such a regime would favor Arctic races of chum, sockeye, and pink salmon. If stocks of these species were planted in suitable streams at the southern end of South America where it projects into the West Wind Drift, the migrating smolts should have little difficulty in finding krill. They simply would have to swim down the temperature gradient until they reached the nearby Antarctic Convergence. Those moving randomly in the current would be swept eastward around the globe in about 2 years, approaching the South American coast from the west as they completed each circuit. Others would probably stay in the dense krill concentrations of the Scotia Sea. In either case, the flow of Andean runoff into the West Wind Drift should lead them readily back to the continent and the streams where they were spawned.

In the short Antarctic food chain, baleen whales have been the principal foragers of krill. Overfishing has now brought these slow breeding mammals to the verge of extinction, and vast populations of krill remain uncropped. Fishery scientists from the USSR have estimated that Antarctic waters could yield annually in excess of 100 million tons, nearly double that of all the rest of the world's fisheries combined. Experimental fishing for krill from research vessels of the USSR and Japan has shown that the energy cost of such a fishery would be very high. It takes a lot of fuel to drive a fleet of large fishing vessels half way around the world and to drag large, fine-meshed nets through rough water in the foul weather that usually prevails in that part of the world.

On the other hand, if appropriate races of salmon could be established in Antarctic waters, they should be able to hunt the krill efficiently and to convert them into an easily accessible, highly nutritious, and readily marketable product. A sensibly managed salmon fishery in the Southern Hemisphere should be both aesthetically and ecologically preferable to fishing for whales. It

should also be an economically desirable alternative to the development of an expensive high seas krill fishery. Development of a successful salmon fishery in the Southern Hemisphere will require extensive international cooperation. Seed stocks and technical and economic assistance will have to be provided to help the countries with the appropriate land and freshwater resources develop the necessary rearing, harvesting, processing, and marketing facilities. Agreements to prevent dis-

tant water fishing fleets from taking the newly introduced salmon stocks on the high seas would have to be developed. However, because the new fishery would be developed in virgin territory, the lack of established fishing practices, customs, laws and special interests relating to salmon should make it less difficult than in the Northern Hemisphere to achieve the international cooperation necessary for developing a rational system for managing the new resource.

Creation of a new, internationally-managed, open range salmon fishery in the presently underutilized waters of Antarctic seas could produce a significant stimulus for further international cooperation in the sensible development and equitable distribution of the untapped wealth of the oceans. It most certainly would lead us a step away from the plundering of the seas so that we may become instead of the pirates that we have been, the gardeners of our planet.

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