DEVELOPMENTS IN ENVIRONMENTAL ECONOMICS~6

MARINE ECOLOGONOMICS

The Ecology and Economics of Marine Natural Resources Management

A. V. SOUVOROV

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The Ecology and Economics of Marine Natural Resources Management

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DEVELOPMENTS IN ENVIRONMENTAL ECONOMICS

VOLUME 6

Marine Ecologonomics

The Ecology and Economics of Marine Natural Resources Management

by

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INTRODUCTION

At present, problems of optimization of the interaction between nature and human society can be solved only by the joint efforts of a wide range of specialists. The elaboration and realization of plans of socio-economic development for individual countries and regions should be based on the principles of preservation of balance in the biosphere, biogeocenoses, landscapes and other natural complexes, and on the principles of rational natural resources management.

Solution of these acute problems requires profound knowledge of the patterns of natural processes and phenomena, in addition to knowledge of economic development patterns, and the ability to use them in everyday life for natural resources management, primarily for evaluation of possible environmental consequences of economic development.

Investigations being carried out in different countries have shown that the effect of human economic activity on natural systems has now acquired a global scale comparable with that of the action of natural forces themselves, and that nature alone cannot, without the active assistance of humankind, preserve and restore its balanced state. At the same time, economic development necessarily involves the production and processing of natural resources. That is why today it is necessary to manage natural resources in ways that do not entail deterioration of the environment, but instead provide conditions for its self-restoration.

Practical recommendations for environmental conservation have their origins in the well-developed sciences of biology, chemistry, physics, geography and others. However, it is ecology that remains the basis for elaborating such recommendations.

Ecology, being a synthetic biological science studying the relations between organisms and their environment, is the scientific basis for optimum natural resources management and environmental conservation. However, the interests of modern ecology extend far beyond the limits of biology. Although at its conceptual level it is a fundamental biological science, in application it is concerned with a whole range of other disciplines, including economics.

A famous researcher, E. Odum, believes that ecology as an independent science had formed by the beginning of the 1900s, but it was only at the end of the twentieth century that the term "ecology" became popular. Most countries that care about the level of their economic development and the living conditions of their people realize the importance of environmental science. As for ecology, it is gradually becoming the basis for interaction between industrial society and nature [1].

In this connection, a new environmental situation, in which the modern economy has to operate, makes indispensable the comprehensive analysis of economic problems from the viewpoint of environmental requirements, and conversely the consideration of environmental problems from the viewpoint of economic development.

Economics has lately become an interdisciplinary science. This refers primarily to its alliance with mathematics – a science possessing the techniques required for exact quantitative analysis of processes and phenomena, systems of proof, and verification of hypotheses. Up-to-date mathematical models and computers have made it possible for ecology to simulate complicated natural processes and phenomena.

The present market economy is characterized by restricted direct administrative regulation in economic development. In Western European countries and the USA economic regulation is exercised by indirect means – taxation policy, control of governmental expenses, improvement of the loan system, decrease in the State's share in the economic system. The activity of government bodies in the social sphere has also been reduced, whereas specific market self-regulation mechanisms play an increasingly important role in countries with developed market relations in their national economy.

One of the advantages of a market economy is the flexibility and resiliency of its regulatory mechanism, aimed at achieving maximum possible profit, and a high degree of business activities among people, stimulated by a wide range of alternatives for profitable capital investments, facilitating, in turn, the achievement of individual progress in the economic sphere.

In my opinion, the main role of the State under the conditions of market economy should be regulation of environmental policy, so that it may become economically advantageous to protect the natural environment. This is particularly important for the World Ocean.

This book is based on the concept of the mutual penetration of ecology and economics, leading to the formation of a common ecological–economic system, at the level of individual countries and whole sea basins. Such a concept involves considering any ecosystem as a unique interrelated functional set of live organisms interacting with human society through their habitat (natural environment). In the opinion of E. Odum [1], the ecological system is the main functional unit of ecology, because it includes both live organisms (biotic communities) and the abiotic environment, these two components being equally important for maintaining life.

As soon as we consider natural resources as a component of the ecological system, we immediately realize that they are an important component of the economic system too, whereas their utilization within either of these systems (ecological or economic) entails their transformation and withdrawal from the other one.

The interaction between the marine environment and economics can be accurately and completely analyzed within the framework of the ecological–economic system, which is more effective than evaluating or forecasting changes in each of these systems separately.

The essence of the principle of rational natural resources management is the determination of optimum loads on both the environment and economy within a unique ecological–economic system. Today, such loads cannot be determined using traditional techniques of ecological and economic analysis. It has become necessary to elaborate completely new methods of environment control and economic development regulation, based on our knowledge of the formation and development of ecological–economic systems.

In this work, we chose marine ecological–economic systems as a subject of our analysis, because the World Ocean plays the most important role in the preservation of the natural environment, affecting the climate on our planet and maintaining a balanced hydrosphere. The ocean also regulates the oxygen: carbon dioxide ratio in the atmosphere; its phytoplankton produces 50–70% of the total amount of oxygen consumed by all the living creatures of the Earth [2].

In the second half of the twentieth century, people began to realize that their economic activity had an adverse effect on the natural environment, particularly the World Ocean, leading to deterioration of human living conditions. The present unfavorable environmental conditions are caused by progressive contamination of the biosphere (including pollution of water, land and atmosphere, acid rain, destruction of the ozone layer, the greenhouse effect and the global warming and ocean water level rise related to it), disappearance of certain species of animals and plants, shortage of clean fresh water. The deterioration of environmental conditions has now acquired a global character and become threatening to life itself.

Human-induced impact affecting the World Ocean is especially dangerous. The World Ocean's stability is high due to the tremendous volume of its water. But, for the same reason, its balance is very difficult to restore once disturbed. In addition, the World Ocean is a "closing element" in all kinds of large-scale processes of substance circulation and transformation, whereas the oceanic branch of the biochemical cycles of vital elements plays an important role in the existence of all living organisms on our planet. That is why the protection of the ocean ecosystem, subject to appreciable anthropogenic impact which has already resulted in serious adverse environmental consequences, requires the joining of efforts from all maritime countries.

Ecological stress is a phenomenon everybody has heard of. It is manifest in the overcatch of fish, the loss of valuable littoral zones as a result of urbanization and intense development of agriculture, and increased concentration of pollutants in ocean water and in the coastal zone – dangerous for human beings.

Intense economic development of seas and oceans, accompanied by the increasing human impact on marine ecosystems, endangers the existence of marine ecosystems. The ocean can purify and assimilate a certain amount of waste without significant ecological deterioration. But the amount and diversity of toxic substances entering oceans and seas do not allow us (at the present level of scientific and technological progress) to evaluate all the economic and ecological consequences of marine environmental contamination.

In addition, the present state of economic development of the oceans is characterized by increasing rate and scale of natural resources production, increasing rate and expanding areas of marine geological prospecting, and by the complicated relations between different branches of national economy involved in marine economic development and the intensifiying impact of human economic activity on the marine environment. All of this, in turn, entails growing costs of optimizing the production of marine natural resources while protecting aquatic and coastal areas against human-induced contamination.

At present, human demands upon marine natural resources is increasing. Thorough investigation and optimum management of these resources are impossible without scientific and technological progress, as all the maritime countries understand. National and international marine economic organizations are forming for the purpose of optimum management of the ocean resources [3, 4].

Today, the management of natural renewable resources is implemented on the basis of a classification system, sometimes called economic–ecological classification, based on criteria of exhaustibility. Biological resources of the World Ocean are included in this classification.

We agree with this classification system, because biological resources are elements of nature. But it does not seem a complete system, because the notion of "biological resources" includes only such aquatic organisms as can be involved in production processes (to meet the demands of human society) under the present level of technological development.

Such biological resources of the ocean are classified in terms of:

- total available resources (total estimated resources of aquatic organisms – which corresponds to the notion of "biomass");
- potential resources (resources that are not readily available, because they have not been sufficiently studied and it is not expedient to exploit them for economic and technological reasons);
- revealed and readily available resources, whose production is economically expedient and technically straightforward.

Some scientists, dealing with the elaboration of theoretical and methodological principles of the economic evaluation of biological resources, and the development of a systems approach to their management, call this set of problems "ocean bioeconomics" [5–13].

In this work, we have tried to avoid using terms "biological resources" or "biomass" when analyzing marine ecosystems of individual sea basins and the ecosystem of the World Ocean as a whole.

Resolutions of the United Nations Conference on Environment and Development (UNCED), which took place in June 1992 in Rio de Janeiro, are very important for the solution of the issues this book deals with, because this conference attracted the attention of the maritime countries' governments to global problems of the rational management and protection of marine natural resources [14].

For the last two decades, hundreds of scientific papers have been published on the problems of ocean contamination and various ecological and economic aspects of this problem [15–46]. However, the majority of these publications are devoted to the problems of chemical contamination of the marine environment, whereas ecological and economic aspects of anthropogenic impact on the marine environment and its consequences have not been paid due attention.

During the same period of time, certain independent attempts have been made to combine ecological and economic studies of human-induced pollution of the World Ocean, but still there is no comprehensive scientific analysis of this problem.

Given that the development of fundamental and applied sciences envisages such integration of ecological and economic studies, reflecting the tendency of modern science to pay special attention to the principal and acute problems of nature and society, the objective of this book is to substantiate the creation and development of a new ecological–economic focus in modern science – marine ecologonomics – which studies changes in the natural processes occurring in the marine environment, in combination with analyzing economic consequences of human impact on marine ecosystems.

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Chapter 1

MARINE NATURAL RESOURCES MANAGEMENT: ECOLOGY AND ECONOMICS

1.1. ECONOMIC DEVELOPMENT OF MARINE WATER AREAS

The World Ocean occupies an area of 362 million km^2 or 71% of the Earth's surface area. Its water volume is 1,362,200,000 m^3 or 97.3% of the water resources on the planet. The vast area and rich natural resources of oceans and seas have always been of vital interest to humankind. The number of countries with access to the sea has always exceeded that of countries deprived of such access, and today about 130 countries of the world are coastal ones [47].

For a long time, sea communications were the link between states and continents located great distances from each other, and it remains the case that more than three-quarters of world cargo turnover is attributed to marine carriage.

Another ancient type of ocean resource use is fishing. The potential of the World Ocean for the fishing industry is tremendous. About 150,000 fish species inhabit the oceans, which allows fishing to be one of the leading forms of economic development of marine natural resources. Fish and fish products have always been very important in the food balance of the population of both coastal and inland countries. Even today, the World Ocean is the source of 15% of proteins and 5% of animal lipids in global food consumption [48].

Scientific and technological progress increases the range of natural resources people use, and marine resources are being developed at ever increasing rates. The problems of research and management of marine natural resources are becoming a matter of great concern. It is hoped that these resources will make up the deficiency in food, raw materials and power suffered by many.

Commercial-scale extraction of such materials as oil, gas, non-ferrous metals (Ni, Mn, Co, etc.) from below the ocean floor has become possible. According to scientific forecasts, the ocean is richer in mineral resources than the land. Over 20 states are engaged in developing oil and gas fields in the shelf zone, and more than 800 such fields are in operation today [49].

Regarding the World Ocean as an object of human economic activity, we must emphasize that during the last several decades the anthropogenic load on marine ecosystems has increased sharply, endangering their self-restoration capacity.

The increasing scale of marine natural resources development was a trigger for setting new international laws for the management of the live and mineral resources of the ocean. This is reflected in the extension of the jurisdiction of coastal states into vast areas of the ocean in the form of special economic zones. This, in turn, has led to re-examination of international legal, economic and ecological approaches to ocean resources management. As a result, the United Nations International Convention on Marine Law was signed in 1982 [50].

As the ocean economy develops, its structure is becoming more and more complicated. In the future, it will be comparable with land production systems in terms of the range and volume of resources of interest.

Intensification of marine economic development requires timely scientific substantiation of how its resources should be managed, new methods of rational economic development, personnel training, and the creation of a material and technological basis to this end. The most urgent objectives are: optimization of natural resources development; substantiation and introduction of the most effective means of production and restoration of natural resources; and problems of environment conservation.

Development of marine natural resources should be coordinated with environment protection, to preserve normal ecological cycles [51]. Natural and economic peculiarities of the ocean should be reflected in the organization of the marine economy – its planning and management.

We understand the rational development of marine natural resources as a system of activities to allow the economically efficient use of natural resources and to create an optimum regime for their restoration, taking into account present and future interests of the marine economy.

Rational development of marine natural resources and natural resources of coastal areas of the land requires the establishment of relations between industry and the marine environment such that economic demands are met at the level of efficiency required by contemporary socio-economic development, ensuring at the same time the conservation of natural resources and a balanced state of the marine environment.

In order to understand the entire mechanism of economic activity in the oceans (including the production, use and protection of renewable aquatic biological resources), let us look at Figure 1.1. Each block of the scheme presents a certain natural process (left-hand set of blocks) which is subject to human economic use (right-hand set of blocks).

What exactly is the *marine economy*? The *marine economy* is a set of industries and their corresponding infrastructure, located mainly in the coastal zone. It ensures the management of marine natural resources and all types of economic activity in relation to their use (including research activities).

The marine economy at present provides the population of the Earth with a considerable amount of necessary food products. The contribution of the marine economy to the world economy grows steadily [52].

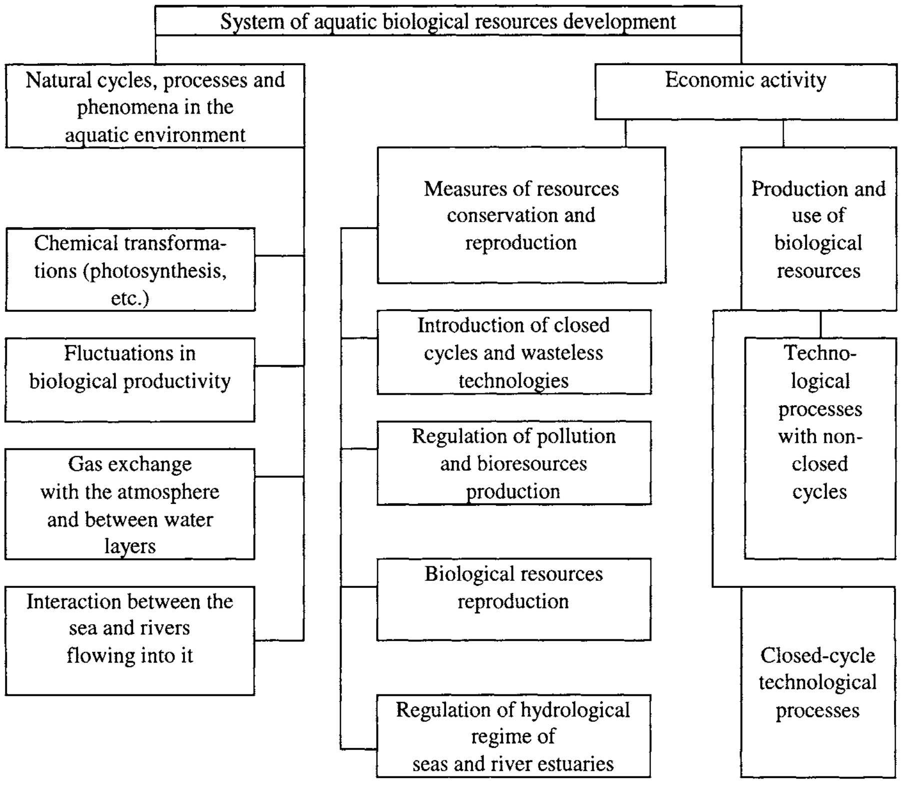

Figure 1.1. Scheme of aquatic bioresources management.

Further expansion of economic activity in the ocean – management of its natural resources, development across its vast area, exploitation of the advantageous coastal position of individual regions – will ensure the progress of the world economy [53]. The science of economics faces the tasks of determining the best methods of conserving and developing marine natural resources, and of elaborating scenarios for the marine economic development of countries located in the ecosystem of particular ocean basins and of the World Ocean as a whole.

Let us now analyze the development of production industries in the marine economy, i.e. industries engaged in exploitation of marine natural resources. Our task is to determine extended standards for the operation of particular technological systems. The following parameters of marine natural resources development should be included in this group of standards:

(1) Z, reduced expenses per unit of the resource produced;

(2) C, cost price per unit of the resource produced;

(3) K, specific capital investments.

The value of Z is determined as

$$Z = C + EK \tag{1.1}$$

where

E is the normative coefficient of efficiency.

Let us plot on the abscissa the value of production funds F:

$$F = \varphi(K) \tag{1.2}$$

where

φ is the normative coefficient.

Let us now plot on the ordinate the value of the cost price C:

$$C = f(K) \tag{1.3}$$

Then the reduced cost Z will be represented by a curve Z_0.

With an increase in capital investments K, the main funds grow and the technical equipment of labor grows too, whilst the cost price of resource production falls. Such a decrease, however, is only observed up to a certain limit (a point with coordinates C^* and K^* on the plot in Figure 1.2). Beyond this, due to the increase in depreciation charges and some other reasons, the cost price begins to grow, even if capital investments are also increased.

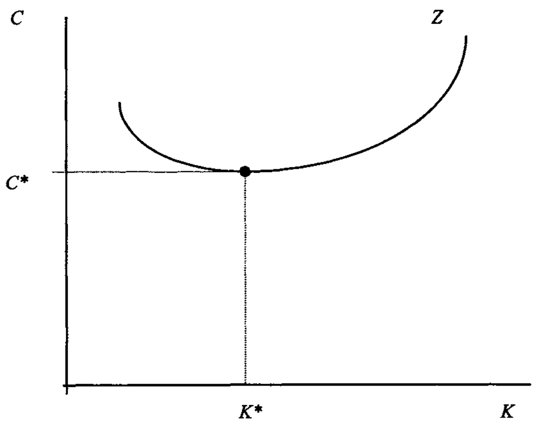

Figure 1.2. Dependence of cost price C on the value of capital investments.

This means that technological improvement must take place for production increase only to the point with coordinates (C^*, K^*), which should be taken into account in any process of marine natural resources management. That is why it is necessary to thoroughly analyze the effect of scientific and technological progress on the dependence of reduced costs on the scale of production. This analysis is relevant in making scientific forecasts of the development of production branches of the marine economy. The rates of such development should correspond to minimum reduced costs for a constant amount of marine resources produced.

Increased competitiveness of marine natural resources creates real economic prerequisites for an increase in the scale of their production. This is true mainly for aquatic biological resources and hydrocarbon raw materials.

The creation of a marine economy in individual regions of the World Ocean should not be a spontaneous process, governed solely by current economic advantage: proper account and correct economic evaluation of marine natural resources, and local natural factors and national peculiarities are relevant.

Comprehensive development of marine economy on the regional and global scale, using the most effective schemes of marine resources management and production, is possible only after detailed investigation of the combination of these resources within particular marine water surface areas and the World Ocean on the whole. Based on the economic evaluation of marine natural resources, their likely development is predicted in accordance with the scientific and technological progress.

Even today, strict regulation of marketable resources exists. Their production and use in individual regions is governed by systems of priorities. The introduction of priorities is a natural response of economics to the deficit in certain types of resources.

Initially, the formation of a marine economy in a region can be implemented on the basis of a system of priorities. Later on, standard cost mechanisms are used.

Economic evaluation of marine natural resources is understood as the comparison of the costs of marine resources production with the profit from their use. Such economic evaluation also takes into account parameters representing the value of resources – both those that are already being used and those potentially suitable for use.

Economic evaluation should consider both traditional and non-traditional types of resources whose inclusion into the economic system is environmentally justified and economically effective. Several groups of problems directly affecting the methodology of evaluating natural resources can be singled out.

The first group includes problems of ensuring a common approach to the elaboration of a system of specific and integral parameters for the economic evaluation of resources.

The second group of problems relates to environmental factors, marine ecosystems' processes of renewal, and regional specificity. The global character of the environmental consequences of contemporary scenarios of marine resources management requires scientifically substantiated plans and forecasts, which, in turn, necessitate the accounting of possible economic loss. Difficulties in solving such problems are connected not so much with accounting the cost of environment protection measures as with evaluating the efficiency of the results of such measures. Here, the comparison of the cost of environmental conservation with the positive results of their implementation is closely related to the problem of evaluating economic loss caused by marine environmental contamination.

The third group of problems concerns the practical application of a system of economic estimates of marine natural resources and the evaluation of damage caused by disturbance of the marine environment's balanced state.

In the ecological–economic approach, the use of resources from an individual marine ecosystem should be preceded by detailed investigation of all the links in the system "ecosystem – marine environment – economy". For example, when elaborating problems of aquatic biological resources production in the near-shore zone, the following important considerations should be taken into account:

- preservation and maintenance of the standard quality of the marine environment;
- transfer from fishing to mariculture, which will ensure increased guaranteed volumes of fish catch and marine products under conditions of high profitability;
- the emphasis in mariculture being mainly on hydrobiont (e.g. mollusk and alga) production, because their biomass and productivity are much higher than those of fish.

Inclusion of the fish industry in the common ecological–economic system makes the following demands on the fish industry itself:

- maintenance of the required water quality;
- maintenance of optimum conditions for aquatic biological resources reproduction;
- improvement of fishing and mariculture techniques;

- ensuring the sale of end products.

The production and processing of marine constructional raw materials are carried out at small depths not far from the shore. The problems of marine mineral resources production are not paid due attention to by most countries, which hampers the development of technical means of resource production and leads to disturbance of the hydrodynamic processes occurring in the coastal zone [54]. Since marine sand is widely used in construction, its production in shelf areas is very useful. However, in many countries it is necessary to optimize the production of marine sand and shell rock, and to substantiate in economic terms the expediency of developing individual deposits of sand and rock, taking account of relevant environmental considerations.

Branches of industry that use marine natural resources as raw materials function mainly in the shelf zone, which is an open system. The open character of this system is the result of external factors characterizing the processes of resource development, the export of metabolic products and the input of industrial waste from coastal areas of the land.

In the future, marine natural resources development will be accompanied by ecological deterioration in the shelf zone (reduction in natural resources reserves, deterioration of their quality, difficulties in economic activities, etc.).

In a production process, the marine economy has an indirect effect on the biological and recreational potential of oceans and seas. At the same time, the exploitation of biological and recreational potential restricts the development of other types of economic activities connected with the marine environment. As a result, conflicts arise from the particular spatial location of individual types of natural resources. These conflicts are compounded by the dynamic character of the marine environment. For example, marine chemical enterprises that affect the hydrochemical regime in sea water are, in turn, subject to the effects of this regime.

Conflicts arise as a result of human economic activity in the coastal zone (mainly during the development of marine sand deposits), such as the implementation of bottom-deepening works, and exploration and production of oil and gas fields in places inhabited by valuable marine organisms [55]. Waste water discharge through the rivers, and pollutant export from coastal areas contribute to disturbances in the natural processes occurring in oceans and seas. Economic activity on the coast, where industrial and agricultural enterprises (including areas of irrigated land) may be located near health resorts, is the most important influence on the ecology of the near-shore zone of the sea. Lately, the effects of hydrotechnical construction have increased in this zone too.

Today there are no environmentally safe types of human economic activity. Even local effects on the marine environment can cause drastic changes in ecosystems, endangering the aquatic biological resources that constitute the raw material base for the fishing industry.

Until recent times, the anthropogenic load on the World Ocean was relatively low, and the amount of aquatic biological resources produced did not exceed the maximum values that would ensure their replacement. The quality of the marine environment was not the factor that hampered development of the fishing industry. However, today, the situation has changed radically due to the exhaustion of biological resources reserves in the shelf zone, caused by over-fishing and intensified environmental contamination. It is the anthropogenic load on the natural environment that prevents us from introducing aquaculture into the shelf zone, because it has made such aquaculture economically inexpedient.

The present state of the marine environment necessitates the implementation of nature conservation measures, but this is hampered by:

- difficulties in measuring changes in the marine environment (because such changes are not always subject to quantitative estimation);
- peculiarities of pollutant proliferation in the sea;
- imperfect methods of evaluating the efficiency of conservation measures for the marine environment;
- underdeveloped techniques of predicting ecological balance disturbance and its consequences;
- the presence of unmanageable ambient factors that affect the environment;
- the lack of sufficient control over the World Ocean ecosystem and marine environment to help eliminate factors that disturb the ecological balance.

The ecological–economic approach to marine natural resources management should provide protection and restoration of natural resources and ensure the quality of the marine environment, maintaining, at the same time, an optimum rate of marine economic development. Note that effective management of marine natural resources is possible only under conditions in which all branches of the marine economy function in ways that maintain the balanced state of the marine environment. The solution of cross-industry and international problems of marine natural resources management is impossible without improving the mechanisms of regulation of human economic activity. Stage-by-stage management of links between different industries, and ecological and economic substantiation of priorities in marine economic development are matters of vital importance.

Finally, we suggest a scheme for economic development of the World Ocean that presents the full range of human economic activity in the oceans (Figure 1.3). The key to the numbers in this scheme are as follows:

1 — biological resources
2 – power resources (heat, tidal, wave, etc.)
3 – sources for maintaining gas balance in the atmosphere
4 – recreational resources
5 – mineral resources of the sea bottom
6 – aquatic chemical resources
7 – fuel
8 – land resources (plots of land allocated for the needs of the marine economy)
9 – heat and moisture circulation
10 – ocean thermocline formation
11 – currents formation
12 – gas exchange with the atmosphere and between water layers
13 – Chemical transformation (photosynthesis)
14 – tides and drainage-zone phenomena
15 – bioproductivity fluctuations
16 – interaction between rivers and seas
17 – closed-loop technological cycles
18 – non-closed technological cycles
19 – disturbances in natural-gas and thermal regimes
20 – environmental pollution
21 – disturbances in biological communities
22 – introduction of closed-loop cycles and wasteless technologies
23 – restrictions on pollution and natural resources production
24 – renewal of biological resources
25 – renewal of mineral resources
26 – regulation of regime in sea and river mouth areas

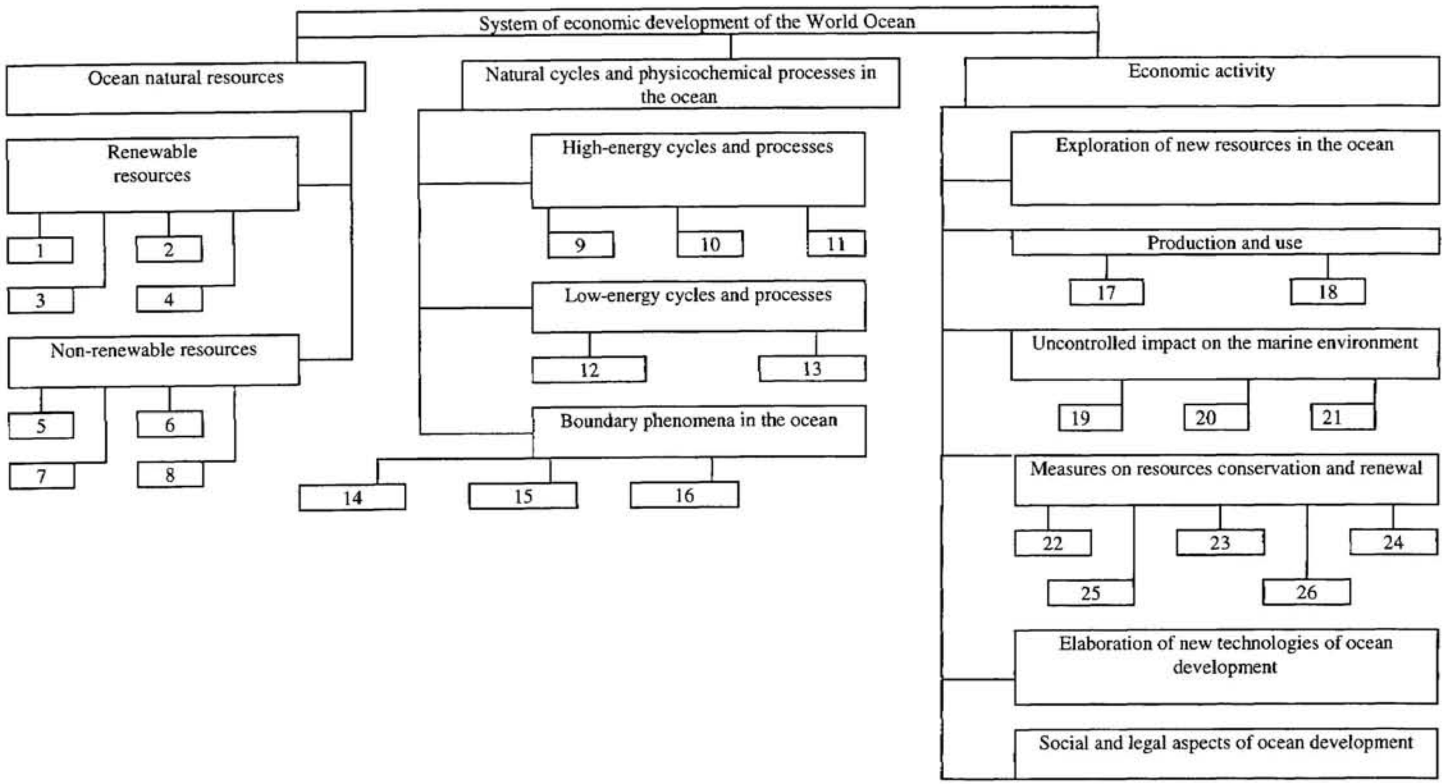

Figure 1.3. Scheme of economic development of the World Ocean.

1.2. Principles of Economic Development of Marine Water Areas

The principles of economic development of marine water areas can be classified into three groups. The first group relates to the economic evaluation of marine natural resources. It includes three principles: the temporal principle, the principle of uncertainty, and the regional principle.

The *temporal principle* is based on the comparison of the expenses and efficiency of the development of a certain type of resources for different periods of time and at different development rates. It is expedient to determine the economic value of raw materials and other types of resources within various time limits, characterizing different engineering and technological conditions of accessibility. For each period under consideration it is necessary to take account of restrictions on the production of particular types of resources, i.e. the introduction of quotas for the production of each type of resource, and also of relevant technological and environmental factors.

The *principle of uncertainty* is connected to high rates of scientific and technological progress, which regulate the scale and structure of demand for marine natural resources.

The *regional principle* is of primary importance for the determination of economic potential and parameters for resource evaluation. This principle is manifest in the differentiation of the natural, climatic, geological and hydrological conditions of individual seas and the socio-economic conditions of their coastal areas.

The second group of principles includes only one principle, which is related to marine natural resources management.

The increasing role of marine natural resources in the world economy requires the elaboration and realization of a global international program of economic development of the ocean. This program should envisage measures for the accounting, protection, evaluation, and use and renewal of marine natural resources. This is the essence of the *program principle* of managing a long-term process of marine natural resources development. In this connection, it seems expedient to elaborate and implement a set of environmental, economic, engineering, social and legal measures that would ensure optimum management of marine natural resources. The various measures (economic, environmental, engineering, etc.) envisaged by the program must be carefully planned, scientifically substantiated, and implemented in a logical sequence.

In order to determine the social and economic effects of such a program, it is necessary to distinguish the main criteria for estimating the interaction between the production sphere and the marine environment. The production sphere should be considered to be one of the stages of substance and energy turnover. If predicted economic demands are met under minimum labor expenses and the preservation of standard environmental quality, the substance and energy exchange between the production sphere and marine environment can be regarded as optimum.

While elaborating an international program of marine economic development, it is relevant to take into consideration the dynamics of marine environmental changes and the process of their interaction with the production sphere.

Finally, the third group of principles relates to the formation and development of the marine economy.

The problems of effective interaction between elements of the natural complex and resource distribution among the branches of marine economy should be solved on the basis of a complex approach to the development of all types of resources. This is the basis for the *principle of complex formation of the marine economy*, which helps us to avoid disturbance of the ecological balance by means of setting optimum cycles of resources use and restoration.

Marine economy formation in a particular sea basin should be based on the laws of the marine ecosystem functioning in the basin. An evenly distributed load on all the elements of the ecosystem can ensure the preservation of biocenoses and their diversity. The structure of the marine economy should therefore be formed in accordance with the aforementioned principle, to provide the possibility of, not only multipurpose use of a natural element of the marine ecosystem, but also optimum and balanced development of all the other elements of the ecosystem. Complex development of the marine economy within a basin envisages the operation of a set of interdependent branches of the economy, which complement each other, taking into account the requirements of biocenosis equilibrium in the basin.

Another important principle is that of *setting priorities for individual types of resources.*

The *principle of concentration, specialization and cooperation* in the marine economy provides the basis for creating multipurpose wasteless industrial enterprises, allowing for optimum use of both natural resources themselves and products of their processing. However, the ecological–economic effect of concentration and specialization in the marine economy has its own limits. Enlargement is possible only up to a certain point, beyond which disturbance of self-regulation and self-correction in the marine environment may occur. Therefore, the dimensions and scale of all branches of the marine economy, its individual enterprises and even single vessels should be optimized, taking account of environment conservation requirements.

All the production and technological systems of the marine economy should be isolated from the marine environment to the greatest possible extent; this is the basis for the *principle of isolation*. For the concentration and enlargement of individual objectives of the marine economy, the *principle of restriction* should be taken into account. This states that the range of marine natural resources production should correspond to its limits, ensuring the preservation of the adaptive capacity of the marine environment.

The ecological–economic approach to the economic development of marine water areas is related, on a global scale, to the optimization of marine natural resources management. This is so, inasmuch as the *principle of integral resources* assumes that branches of the marine economy competing for the same type of resources will damage each other, and the degree of this damage will depend directly on changes in the ecosystem caused by the activity of all these branches: the more they modify the jointly used ecosystem (or an element of it), the greater the damage they do to each other.

Large production units have great financial and technical potential to improve their technology. In addition, concentration in the marine economy creates favorable conditions for environmentally safe management, because the feasibility of using raw materials and of utilizing wastes largely depends on the scale of production.

The *principle of ecological regulation* envisages singling out a whole set of problems related to marine environment conservation, and including them in the structure of territorial and branchwise management of the marine economy.

Owing to the fact that at present the problem of environment conservation has acquired a global character, its solution requires coordination of the efforts of individual countries. The marine economy of each country has now become dependent on the marine ecosystem as a whole. Comprehension of ecological interdependence is a new phenomenon in the development of the marine economy.

It is worthwhile to determine the most effective form of organizing the formation of the marine economy in a particular region, allowing for optimum use of both marine and terrestrial resources in the region. The natural resources and conditions in an individual region affect the character and forms of marine economic development, and the organization of industrial production in the coastal zone [56].

1.3. Ecological–Economic Regionalization

One of the principles of economic development of the World Ocean is the regional principle, considered in the previous section. This principle is the basis for the spatial differentiation and regionalization of water areas.

A considerable amount of "spatial" information has been accumulated in the process of marine research and economic development. One of the most widely used methods of generalizing and processing such information is the regionalization of ocean and sea areas, distinguishing structurally organized natural–economic units within an individual ocean or sea, or within the whole World Ocean.

Regionalization is a special type of spatial differentiation, understood as dividing the whole into individual units (regions) characterized by particular spatial organization and peculiarities [57].

Regionalization of the World Ocean lags behind regionalization of the land. Natural regionalization has become widely used, whereas economic regionalization is quite a new phenomenon. However, a complex approach to marine natural resources management necessitates *ecological–economic regionalization,* which takes into account not only human impact, but also the state of the environment.

The international situation in the World Ocean – the proliferation of 200-mile zones of jurisdiction set up by coastal states – has intensified the regional aspect of economic development. The numerous environmental, political and economic problems connected with marine natural resources production and use can be solved only under conditions of mutual understanding and international cooperation [58].

Special attention should be paid to one basic difference between the regionalization of land areas and of water areas. Economic regionalization of land areas consists mainly of the regionalization of economically developed territories with their own industrial structure. Ecological–economic regionalization of sea water areas is implemented in a process of economic development (at different levels of a spatial hierarchy), resulting in the formation of individual (from the viewpoints of ecology and economics) water area units. In addition to the ecological interdependence between individual water areas, stable links with coastal areas are typical of the ocean.

Taking into consideration the specific features of the regionalization of land and water areas, let us consider some principles of ecological–economic regionalization.

Any analysis of regionalization should be based on the existence of ecological–economic regions. Our deliberations on the economic development of the World Ocean, preservation of its natural environment, global monitoring, etc. will be meaningless if we do not acknowledge the fact that individual ecological–economic regions do actually exist. In fact, many ecological and economic problems are of a regional character.

Thus, *ecological–economic regionalization of the World Ocean* involves singling out integral existing water areas which have their own economic links with the land and their own specialization and systems of environmental monitoring.

The process of regionalization should take into account the degree of economic development of coastal areas, the combination of natural resources, and the existence of large industrial and cultural centers. This is the basis for the first principle, which we call the *principle of integrity*.

In accordance with the general theory of systems, ecological–economic regions thus distinguished should be integral objects, which really exist. The integrity of the region should be both ecological and economic. Ecological integrity allows the restriction of human impact on the marine environment in the given region. Economic integrity should allow the inclusion of all the objectives of the marine economy within the framework of the region. These requirements are observed for aquatic biological resources, as these resources are components of the ecosystem within the given region. However, it will be difficult to apply this principle to other resources. This is because reserves of mineral raw materials and other resources can be discovered located beyond the limits of an individual ecosystem. The necessity of such inclusion is, however, evident; otherwise, the region's integrity with respect to its economic activity would be violated even within the limits of separate entities of the marine economy.

Marine ecological–economic regions have a certain peculiarity in that the largest and most important economic centers of the World Ocean are formed in the land–sea contact zone.

The second principle of the regionalization of sea water areas is the *program principle*, which envisages preliminary elaboration of a project of marine natural resources management within the given basin. Economic regionalization helps us to single out structurally organized spatial systems, thus creating the basis for management. In contrast to economic regions of the land, where management and control are implemented according to an administrative–territorial principle (and a program principle in only a few places), ecological–economic regionalization of the World Ocean should be carried out with a purpose-oriented approach, with the creation of comprehensive programs for each region. Each such program must have a single leader, responsible for its realization.

In the analysis of practical aspects of ecological–economic regionalization, water areas controlled from adjacent coastal territories should be distinguished within the shelf zone. This is for the following reasons:

- mineral deposits on the shelf are the continuation of land deposits;
- economic activity in the coastal zone has a negative effect on the ecosystems in the near-shore zone.

The superposition of maps of known mineral raw materials deposits can be useful for the realization of both principles described earlier. In the network of regions thus obtained, water areas controlled from the shore are singled out. These zones are distinguished by continuing the line of administrative boundaries perpendicularly to the shoreline until they cross the external boundary of the water area within a 200-mile zone. When this is impossible, the boundaries between water areas should be determined by agreement between the neighboring countries.

The question of determining a *subject of control* over marine ecological–economic regions is of primary importance, because it determines the potential for rational management of marine natural resources in the interests of the whole economic complex. Economic management in regions where the interests of several coastal areas are concentrated should be implemented by the single administrative body of a large region (in some cases, this can be an international board or council), which regulates natural resources management and relations between different territories within a larger region.

The main advantages of ecological–economic regionalization of sea water areas are as follows. First, it allows us to take into account the state of the environment under any scenario of marine economy development. Second, it makes it possible to estimate the quantity and quality of marine natural resources, as well as the technical and technological potential for their production.

The ecological–economic approach to marine natural resources management requires assessment of ecological, economic and spatial differentiation. Spatial differentiation allows us to single out the following economic zones in the ocean zone of the open ocean; island zone; and land–sea contact zone (which includes the continental shelf).

The *economic zone of the open ocean* is characterized by extensive development. In this zone, the following areas can be singled-out: areas of production of surface water resources; areas of production of the resources of the near-bottom active layer; and a reserve zone that can be used only for the purpose of research.

The *island zone* plays a very important role in marine natural resources management. In the future, many islands, especially those located in warm climatic belts, may become centers of economic development of the World Ocean.

Recently, many researchers have been paying special attention to the land–sea contact zone, where physical, chemical, geological, hydrophysical, hydrochemical and other types of interaction between land and sea are most pronounced. As a result, numerous theories and concepts have been put forward, such as the geographical concept of the active ocean surface, the geomorphological theory of marine shoreline development, the ecological concept of the boundary layer, etc.

The natural–economic *land–sea contact zone* includes coastal areas and the continental shelf. Such areas can be distinguished by their indissoluble links between water areas and the shore. Let us call this part of the coast the "shore zone". It is here and on the continental shelf that the main economic activity in the World Ocean is concentrated.

Determining the external boundary of the shore zone is a difficult task. In some countries, it is determined by law. It does not seem expedient to us to set a common definition of the shore zone width (1, 3, 10, 100 km or more). The ecological–economic approach should be used, taking account of regional natural and economic peculiarities, and the degree of contact zone development. The shore zone width can therefore vary. The existing principle of singling out natural–economic coastal zones testifies to this. For example, the Russian sector of the Arctic includes several administrative regions and autonomous territories. This Arctic shore zone is defined taking account of transport accessibility – proximity to the Northern Marine Way. The shore zone width here therefore varies from several dozen to several hundred kilometers [59].

The natural–economic land–sea contact zone is characterized not only by its appreciable size and diversity. It is in this zone that the largest centers of economic development of our planet are located. Many of these centers were formed as outposts of pioneer development of continental areas. Now they can boast of having the most favorable conditions for economic development of the ocean.

The land–sea contact zone is a complicated natural system; it is in fact the filter of the planet. Natural processes occurring here play an important role in the global turnover of substances and energy. At the same time, this zone is most sensitive to external impact, which is becoming ever more pronounced. It is in this zone that ecological and economic problems, arising from coastal and shelf area development, manifest themselves most clearly [60].

The proximity of different industrial enterprises to the coast, and the high dynamism of the systems operating in the land–sea contact zone cause high "competitiveness" in its functions, because of intense activity of natural processes there. Therefore, it is important to solve the complicated problem of spatial organization of the land–sea contact zone, taking account of the particular problems of managing its resources.

The marine component of the land–sea contact zone consists of inland seas and/or continental shelf. The area of the natural–economic land–sea contact zone constitutes 7% of the Earth's area, while the length of its shoreline is over 1.5 million km [61].

The *continental shelf* is understood to be the surface and subsurface of the sea floor in marine areas adjoining the continental coast or islands. This zone can extend to points where the water depth reaches 200 m or more. The ocean bottom in depressions located on the continental shelf massif forms an integral part of this shelf [62].

Natural resources of the continental shelf are the property of individual countries. Prospecting and production of these resources, along with research, can be carried out here only in accordance with the current legislation of the countries to which these shelf areas belong.

Natural resources of the continental shelf are defined as the mineral and other inanimate resources of the sea floor surface and subsurface, and the living organisms, whether attached to the sea bottom or above it, or moving over it. Such organisms include crustaceans, mollusks, marine herbs, algae, etc.

Economic development of the land–sea contact zones, including their natural resources management, is determined by a whole set of administrative, economic, ecological and environmental factors. A highly developed industrial base on the coast, capable of ensuring worthwhile natural resources production, restoration and conservation, and the implementation of environment conservation measures are important factors in the economic development of the land–sea contact zone [63].

The main prerequisite for economic development of the land–sea contact zone is a reliable *raw material base,* understood as known reserves of mineral, chemical, biological, power and other resources which are used at present or could be used in the future.

When using the ecological–economic approach to management of the land–sea contact zone, we must be guided by the criterion of expediency, based upon the objective integration trends in the economy.

The ecological–economic approach to natural resources management in the land–sea contact zone envisages their comprehensive development, combined with partial "reservation" of certain water areas for the purpose of maintaining their ecosystems' stability. The same reservation should also be implemented in the shore zone [64].

The problem of ecological–economic regionalization of the World Ocean, being much more difficult than that of regionalization of continental areas, has not been sufficiently studied. This is because of the continuity of the aquatic environment, the strong correlation of all the processes occurring in it, and the inertia of the ocean. It is owing to this inertia that changes caused by disproportionate economic development of water and land areas begin to manifest themselves only after a long period of time. Besides, the existing natural and administrative borders, and the boundaries set up according to the branchwise principle can no longer serve the purpose of rational economic development of the ocean – geological, fishery, transport, etc.

Optimum management of marine natural resources is impossible without ecological–economic regionalization, based on the following dependence: "demand in natural resources → the natural resources themselves → possibilities for their production and use".

The main difference between ecological–economic regionalization and other types of regionalization is the assessment of environmental conditions, in addition to the quantity and quality of natural resources and the possibilities for their production. The main task is to locate a region for prospective development using a set of parameters whose composition and variation limits should be determined by the character and peculiarities of a concrete economic problem that needs to be solved. Parameters of resources and environmental conditions (both constant and variable) should be studied, as well as parameters characterizing the economic demands of the society and the existing potential to meet these demands. Spatial and temporal variations in these parameters must also be taken into account in order to determine the ranges of their application.

Ecological–economic regionalization of the World Ocean is also relevant for long-term planning of its economic development.

A systems approach to ecological–economic regionalization allows us to locate regions where the interests of different branches of the economy and different countries are in conflict. This concerns (mainly): oil and gas production; fishing; the health resort industry; and marine transport. The systems approach allows us to specify the parameters that become sources of conflicts, and to find compromise solutions from analysis of these parameters.

The following concept is the basis for ecological–economic regionalization. A certain economic problem to be solved with the help of regionalization should be set for a long yet strictly defined period of time (e.g. 30–50 years). Such a long time period is necessary because a consistent long-term strategy of economic development will ensure increased capital investment efficiency and decrease in expenditure. Any reorientation in this domain can result in tremendous capital expenses, waste of time, and decreased labor efficiency [59].

Regionalization of sea water areas should be implemented in such a way that existing and projected ecological–economic regions may form a unique system of areas, facilitating the solution of individual economic problems. Thus, marine, continental, and land–sea contact zones should form a complicated system of spatial distribution of productive forces, capable of meeting the increasing economic demands of the Earth's population with minimum labor expenses.

Therefore, natural processes and human economic activities should be synthesized into a common ecologonomic system, formed with the help of regionalization.

1.4. What is Marine Ecologonomics?

Careful study and management of marine natural resources have become characteristic features of world economics. Substantial capital investments and material and labor resources are made available for studying the ocean and making use of its resources, and for developing the economy of coastal regions. When determining the direction of economic development of ocean and coastal areas, it is necessary to take into consideration a set of complicated economic, environmental, social, legal, political and technological problems. The following economic problems have become the most important ones:

- elaboration of a general fundamental theory of ocean management;
- investigation of methods and principles of formation and functioning of different branches of the economy and of interbranch regional and national oceanic economic systems;
- substantiation of patterns and stages of economic development of ocean and coastal regions.

The main theoretical goals of the economics of ocean resources development are to study the effects of the laws and patterns of this branch of knowledge, and to investigate principles, factors, methods and peculiarities of multipurpose economic development. This relates closely to social and ecological–economic principles, natural and artificial renewal and extraction of marine natural resources, and marine production output.

Given that the economics of the ocean is a branch of economic science, the study of patterns in the development of productive forces and production relations under the specific conditions of interaction between humans and the marine environment (ocean economic studies), should be based on the following principles:

- optimization of production, taking into account the preservation of the balance of nature in the ocean;
- improvement of labor division, ensuring efficient management of ocean resources and development of the marine economy and the economy of coastal areas.

From the standpoints of both theory and practice, ocean economic research can be regarded as having three stages.

The first stage is the elaboration of the general theory and scientific substantiation of branch and regional patterns of development of the marine economy as an integral part of a country's national economy.

The second stage is the study of the interrelationship of the world and regional ocean economic systems.

Finally, the third stage involves the study and elaboration of methods of purposeful and carefully planned formation of specific marine economic systems – on both a global and a regional scale.

According to the objects of investigation, scientific problems of ocean resources management can be classified into three groups. The first group of problems relates to the investigation of:

- trends and after-effects of economic development of the ocean;
- socio-economic aspects of economic development of coastal regions;
- marine transport development;
- regulation of international legal norms for ocean resources management;
- environmental problems of ocean economics;
- forms, tendencies and consequences of economic management of the ocean in different countries of the world;
- multipurpose economic development of the World Ocean.

The second group of problems is connected to the study and elaboration of methodological principles of complex economic management of ocean resources (biological, mineral, power).

Economic evaluation of these resources is the most common problem, and determines the efficiency of resources management. The main task here is to elaborate general methodological principles to estimate the resources in question, taking into account the specific conditions of the marine environment. Particular features of certain types of resources necessitate elaborating individual methods for their economic evaluation.

Interbranch and territorial problems of complex economic development of the ocean pertain to the third group of problems. The most important are: economic problems of construction in the sea and in coastal areas; development of new technologies and improvement of existing methods of extraction and processing of marine natural resources; problems of the formation and development of territorial–industrial complexes and their regional branches.

Research into the economic management of the ocean and its coastal areas can be classified as fundamental or applied research. Fundamental studies of the ocean comprise investigations on the physics, geophysics, geology, geography, chemistry and biology of the ocean. To a certain extent, economic studies can also be regarded as fundamental, in particular, the elaboration of methodological principles for the creation of national and regional comprehensive development programs. Applied research includes studies concerning the development of the biological, power and mineral resources of the ocean, and using the ocean as a transport line. Applied economic research comprises the evaluation of multipurpose ocean management and the development of coastal areas, various socio-economic, legal and political studies, and estimation of the efficiency of the studies conducted (both fundamental and applied).

If the economics of marine natural resources management is based on today's knowledge alone, then, due to the inertia of the processes occurring in the marine environment, it will be, at best, the science of yesterday. Economic calculations should therefore be based on forecast and prospective–strategic data. In addition, the economic efficiency of measures aimed at rational development of marine resources should be considered not only in terms of the difference between income and expenses, but also in terms of their socio-economic value, determined by the development of society, including its relations with the ocean. Therefore, any economic calculations should be supplemented by social and ecological–economic calculations, which should be of predictive character.

Under the conditions of a "threshold" resource situation, economic criteria may change from purely economic to ecological–economic. Simultaneously, the significance of monetary evaluation of natural resources in general and ocean resources in particular also changes. Money is transformed from a purely economic instrument into a carrier of information about the ecological–economic and social value of a particular type of resources. Natural processes occurring in the marine environment and human economic activity are synthesized into a unique ecological–economic system – in other words an *ecologonomic system.*

It should be noted that evaluation of the "ecological" expenses of economic development is a very complicated issue, whose solution is affected by the development of the marine economy. Until recently, ecological expenses were neglected by classical economics; they were regarded merely as "external factors" outside the scope of interest.

If marine natural resources management were based only on the use of wasteless technologies, then any damage caused to the marine environment (and measures of its conservation) could be reduced and later eliminated. Thus, it might be possible to move from marine environment protection to the elimination of the very necessity for such conservation. In the future, this will probably be the main trend in solving marine environmental problems. A marine economy based on wasteless technologies will no longer damage the marine environment, but, instead, will make possible its effective restoration. If humankind stops considering the World Ocean as a gutter for all kinds of waste, but, instead, uses it as a testing ground for newly developed wasteless technologies, then these technologies will contribute to the optimization of marine natural resources management. In this way, environmental conditions can be improved, and not caused to deteriorate. Thus, the necessary conditions will be achieved for excluding antagonism from the system "economy – marine environment" (and antagonism between humans and nature in general).

In the opinion of the American scientist Barry Commoner [65], the Earth's ecosphere is a product of the joint evolution of live organisms and the chemical and physical components of the Earth's surface. From the viewpoint of a human's lifetime, the progressive development of the ecosphere is slow and irreversible. Therefore, the ecosphere is indispensable: once destroyed, it will never be restored – either by natural processes or by human effort.

The main functional element of the ecosphere is the *ecological cycle*, within which each element affects all other elements and, in its turn, is affected by them. A totality of ecological cycles forms an ecosystem.

The World Ocean is an integral ecological system. And if economic processes are regarded as a means of providing distribution and use of marine resources, then the stability of the ocean ecosystem, ensuring permanent availability of all the required resources in it, becomes a prerequisite for successful functioning of the marine economic system. Thus, the functioning of the economic system should be compatible with the functioning of the ecological system.

Ecology is a synthetic biological science, studying the conditions of living organisms' existence and their interaction with the environment. At the same time, ecology is a scientific basis for the rational management of natural resources. However, the interests of modern ecology have extended far outside the framework of biology. Although at its conceptual level ecology remains a fundamental biological science, in its applied branches ecology utilizes a wide range of other sciences, including economics. In this respect, modern ecology as a science is subdivided into general (theoretical) and applied ecology. Applied ecological studies have their own independent character and are considered as independent branches of ecology [66–71].

In contrast, the new ecological situation in which modern economics has to function necessitates a comprehensive analysis of economic problems from the viewpoint of environmental demands, and the analysis of ecological problems from the viewpoint of economic development standards. Thus it has become important to study systems of the type "ecosystem–environment–economics". In the case of the functioning of ecosystems in the marine environment, this becomes the system "ecosystem–marine environment–economics".

All this requires a holistic concept of a marine ecosystem. Communities of marine organisms (like any other organisms on the Earth) have a certain unity with the environment, i.e. they constitute a system within which processes of energy and substance transformation occur.

The ecosystem is the main object of current environmental studies. It is an elementary functional unit of living nature, because it includes both biotic and abiotic factors. Note that, from the quantitative viewpoint, an ecosystem includes a totality of organisms and their habitats in which the volume of internal exchange exceeds that of external exchange. Thus an ecosystem can be defined as a combination of life and environment, characterized by a certain degree of stability and a pronounced internal turnover of substances.

In the opinion of the famous Italian economist Epicampo Corbino [72], economics, "now and forever", will have to take into account additional expenses related to environmental factors. Since it is impossible to neutralize the harmful effects of certain branches of production, we shall have to prohibit them in order to preserve the environment. Reforms in some other branches of industry will be required, and part of the costs of this, especially those allocated for the elimination of the consequences of possible increase in unemployment, will be a burden on the shoulders of the whole of society. New problems will arise in the domain of price formation, because various expenditures in the production sphere will increase.

From now onwards, a new branch of economic science will play an important role both in theory and in practical life. Corbino calls this new branch "economics of the environment". In his opinion, the costs of environmental preservation should be distributed among different countries and economic agents, including the private sector.

The Australian Professor Edward Nowotny assumes that if a certain upper limit of economic and demographic growth can be established (determined by ecological and resource factors), then "overcoming" this limit will be possible only with changes in the internal structure of developing aggregated economic systems [73].

The works of Academician T.S. Khachaturov are devoted to problems of interaction between nature and society, and the presentation of such interactions in terms of economic laws and categories [74].

The concept of the ecological–economic system, put forward by Professor M.T. Meleshkin in 1980 [75], is based on the fact that the mutual penetration of ecology and economics has become more pronounced. Such processes form certain independent integrities, necessitating their regulation within the system "economics–marine environment". Meleshkin assumes marine resources to be an important component of both economy and ecology. The use of marine resources in one of these spheres means their withdrawal from the other one, which determines the character of interaction between these two spheres. Thus, system-forming relations between them are created as relations of interaction. The essence of such interaction is that ecology forms a system of constraints (determining the limits of possible anthropogenic load on the environment) within which an ecosystem can function. These constraints are system-forming factors in the development of a marine economic–ecological system.

We consider this approach to be somewhat limited, because it neglects the notion of the ecosystem. Without this notion, the study of both ecology and economics is hampered. Meleshkin's ideas on the subject of economic–ecological studies are therefore incomplete.

Note that the concept of an economic–ecological system, put forward by Meleshkin, is not new. It was adopted by him from the work of Professor P.G. Oldak [76], who had put forward a hypothesis of a bioeconomic system. Oldak had a more profound understanding of the processes occurring in the biological environment.

Therefore, in order to study ecological–economic systems, one has to be not merely an economist or an ecologist, but to have some knowledge of both these sciences. This is a peculiarity of interdisciplinary studies. (For example, this author was educated first in ecology and later completed a dissertation in economics.)

When we speak about the ocean as a unique ecosystem, we assume this to be an elementary functional unit of the biosphere [77]. Any ecological system is dynamic, since the unity of all the living organisms forming it constantly changes in a process of interaction with the physical environment [70]. This interaction causes the formation of an energy flux, resulting in the diversity of organisms and the turnover of substances within the ecosystem.

If the environment is relatively stable, the ecosystem preserves its own stability. If the environment changes, various changes will occur within the ecosystem, including its self-support and self-regulation functions (adaptation). The ecosystem's facility for self-support and self-regulation is called *homeostasis*. Under natural conditions, homeostasis is ensured by the interaction between substance turnover and energy fluxes in the ecosystem. Self-corrected homeostasis does not require any external control.

Marine environment stabilization is ensured by a set of physical, chemical and biological mechanisms. This facility for self-regulation and self-correction has certain limits, beyond which changes in the main parameters of the ocean will occur. This is why, in a process of marine natural resources management, the ecological and economic systems of the ocean interact with each other, forming a unique ecologonomic system. In this system, ecological processes occurring in the marine environment become the main processes, whilst the task of economics is reduced to the evaluation of damage and the cost of marine environment conservation. Thus, a new science – ecologonomics – is formed at the interface of ecology and economics.

The self-regulatory character of the ocean ecosystem deserves special attention, as it ensures the stability and permanent functioning of the ecosystem. Self-regulation can help us describe both the process of marine environmental degradation itself and the factors causing it. Ecological degradation of the marine environment can be regarded as a process affecting the ecosystem so much that it reduces the adaptive capacity of the latter and causes irreversible changes in it, leading to its destruction.

It should be noted that the factors affecting the ecosystem in the manner described earlier are external ones, i.e. their effect comes from outside the ecosystem. In the case of any internal changes in the quantity and/or functioning of any biological element of the ecosystem, automatic restructuring of the latter occurs due to its property of cyclicity: any element of the ecological cycle affects all the other elements, and is, in turn, affected by them.

Internal changes in the ocean ecosystem caused by external factors are complicated non-linear processes, which are not so easy to describe using quantitative parameters.

Ecological expenses of any economic process should be expressed quantitatively. In general, they constitute a scale of the impact of any internal factor on the marine ecosystem's environment, violating that environment's adaptive capacity.

However, our ideas on the balanced state of marine ecosystems are contradictory. On the one hand, we observe appreciable permanence (in other words, a balanced state of the marine ecosystem). On the other hand, we are faced by varying degrees of stability and/or lability in ecosystems. The investigation of specific relations in marine ecosystems provides the basis for scientific forecasting and calculation of changes caused by external factors: disturbance of the balanced state of marine ecosystems results from variations in the intensity of processes occurring within it.

It is also necessary to take account of violation of the ecosystem's balance caused by the interaction of ecosystems – a regular process of substance and energy exchange, which takes place everywhere. It is this process that causes the formation of ecosystems with different degrees of stability. This is a chain of evolutionary changes, where new relations replace the old ones gradually or abruptly, causing the restructuring of inter-ecosystem and intra-ecosystem relations.

The new science of ecologonomics has its own research objectives, methods, categories and principles, i.e. everything that is typical of any other science. Up until now, this science has been in the stage of formation, and we hope that this book will contribute to its development.

The principal *method* of ecologonomics is ecological–economic analysis envisaging economic evaluation of marine ecosystems, taking into account patterns in the formation and development of organisms' populations, their interaction and quantity dynamics.

Ecological–economic or ecologonomic analysis comprises:

- investigation of patterns in the formation and development of biocenoses by means of studying marine organisms and their habitats;
- economic evaluation of the effects of marine organisms' response to the impact of pollutants, and determination of critical concentrations of the latter.

Thus, marine ecologonomics is closely related to studying environmental consequences of human impact on the ocean ecosystem, including the effects of withdrawal of biological and mineral resources from the ocean and the use of its energy resources. Moreover, its main task is to provide economic evaluation of the above effects for the present and future.

One of the main problems related to marine environment contamination is ecologonomic monitoring. In addition to providing necessary information on the state of the ocean environment, this monitoring envisages the appropriate introduction of economic sanctions for ocean contamination and ineffective use of marine natural resources.

Contemporary science has spent much time developing a body of mathematics for the elaboration of an optimum pattern of natural resources management, taking into account the factor of resource deficit. However, overuse of mathematical methods often leads to the substitution of methodology by formalized description of ecological and economic phenomena. One of the most important *techniques* of ecologonomic studies should therefore be the express method, based on expert–empirical principles. This method was successfully used for the elaboration of strategic directions for marine natural resources development and pre-project estimations of anthropogenic effects on the environment.

Nevertheless, the role of a body of mathematics in the development of ecologonomics must not be underestimated. In this respect, we suggest applying simulation modeling, which does not require strict formalized description of the ecologonomic system – it is sufficient to know the algorithm of functioning and interaction between the economic and ecological systems of the ocean. This algorithm can be assigned in a descriptive manner and then serve as a basis for development of computer programs.

When such an approach is used, emphasis is laid on the possibility of introducing realistic assumptions in the analysis. This is because, usually, simulation models are developed to obtain answers to concrete questions, and, taking into account the capabilities of modern computers, it is not worthwhile restricting oneself by using too many simplifying assumptions in the model. A simulation model can fully reflect the peculiarities of a real ecologonomic system and the interrelationship between its individual parts. The model has a block (modulus) structure, allowing us to correct it easily, taking into account new knowledge of economic and environmental processes.

The *objects* of marine ecologonomics investigations are as follows:

- peculiarities of the manifestations of economic laws in marine resources management and the effect of the marine economy on the ocean environment;
- peculiarities of the standardization and forecasting of marine environment quality;
- effects of scientific and technological progress on the rates and parameters of marine resources management and on the World Ocean itself;
- methods of economic substantiation of the optimum use of marine natural resources (including their restoration) and marine environment protection;
- economic mechanisms for stimulating marine environment conservation;
- perceived trends in marine natural resources development, taking account of environmental quality;
- methods of economic evaluation of marine natural resources from the viewpoint of the damage caused to them by their abuse.

It is expedient to begin investigation of each ecologonomic problem with the elaboration and analysis of future development scenarios, i.e. any situation that might occur under various political scenarios. Initial scenarios for ocean natural resources management should be elaborated on the basis of logical assumptions reflecting general trends in development and possibilities for actively affecting the development process. At this stage, the previously-mentioned express method should be used. Simulation modeling should then be used, necessitated by the need for integral analysis of a whole set of problems facing any ecologonomic system at different stages of marine natural resources development.

In solving ecologonomic problems, we must be guided by the following principal criterion: "If the solution of a particular ecologonomic problem ensures an increase in marine natural resources exceeding the amount of resources required for the solution of a particular production problem, then marine economics takes the line of ascent, and the ecologonomic system demonstrates its viability. If ocean resources grow more slowly than the demand for them, then the development of marine resources is approaching deadlock, economic growth ceases, and the ecologonomic system becomes no longer viable."

Chapter 2

ECOLOGICAL–ECONOMIC FUNDAMENTALS OF MARINE NATURAL RESOURCES MANAGEMENT

2.1. Ecologonomic Principles of Marine Natural Resources Management

The role of the ocean in providing living conditions for various organisms, including human beings, can hardly be overstated. In the opinion of many scientists, life first appeared in the ocean, and 75% of classes and subclasses of all living organisms on the Earth were engendered in the water. At present, there are over 300,000 species of animals and plants in the ocean: from microscopic algae to gigantic 160-ton blue whales. The overall annual oxygen production by marine plants is 36 billion tons, 70% of the total amount of oxygen in the atmosphere [78].

The ancient Greeks assumed the ocean to be a river flowing over the whole Earth. Today we understand the ocean as water space of the planet.

All continental bodies of water differ (sometimes appreciably) in their water quality, their relations with each other, and – more importantly – in the chemical composition of their water. In contrast, the ocean is characterized by the stable chemical composition of its water. Halogens prevail here: 88% of the total amount of dissolved salts consists of chlorides; that is why ocean waters are often called the "halosphere". Carbonates prevail in continental bodies of water.

Another peculiarity of ocean water is its consistent salt composition. Ocean water salinity is measured per mille (the number of gram of salts in 1 kg of sea water). It varies from 1 to 40 per mille, the average value being 35 per mille. But, no matter how high or low the ocean water salinity might be, the ratio of the total amount of salts (S) to the concentration of chlorides (Cl) – the chloride coefficient S/Cl – is constant for the whole World Ocean, and equal to 1.805. Even in near-shore areas of seas, where the input from the land is appreciable, the chloride coefficient remains close to 1.805 [79]. The stability of sea water's salt composition and the low spatial variability in its salinity promote the proliferation of life in the ocean. We consider this most important feature of ocean water to be the basis for our concept of marine ecological systems, taking into account the fact that the notion of the ocean ecosystem can be applied to ocean units of different types and dimensions. The ocean ecosystem is characterized by high water mobility and mixing capacity. The water–salt balance in the ocean is determined both by global factors, such as geographical latitude, and local ones, such as the effect of coastal areas, continental runoff, bottom topography, shoreline configuration, etc. [80]. This is the basis for singling out individual zones in the ocean which differ in their physicogeography, biology and other features. Further, we can proceed from the analysis of the whole ocean ecosystem to analysis of the ecosystems of individual sea basins. This is possible because seas are much smaller than oceans, and the water in the seas may differ greatly from sea to sea, because the seas are isolated from the bulk of the ocean water mass. *Sea basins* are intermediary between seas and oceans. A sea basin can include one or more seas, whose ecosystems should be analyzed at pelagic and benthic levels when one is evaluating the economic efficiency of mariculture.

Global mechanisms of energy and substance transformation, caused by uneven heating of the atmospheric air and water surface, as well as by vertical circulation of ocean waters, operate in the ocean. Huge masses of water, absorbed heat, mineral and organic substances, and dissolved gases allow the ocean to control the planet's substance exchange and dynamic water balance. Water's transparency and high heat capacity make the ocean a thermal regulator of the Earth. It is the ocean that determines most of the peculiarities of habitat for the plants, animals and people living on the planet.

Most marine plants are microorganisms of the phytoplankton type, which form the primary product of the sea. Their total annual production in the ocean is estimated at 500 billion tons [77]. This primary product is the basis for the existence of other marine organisms – zooplankton, mollusks, fish, birds and aquatic mammals. Free-swimming animals (fish, cephalopods, mammals) have the greatest practical importance for man. The production of such animals is estimated at 200 million tons (including inedible species) [81].

In addition to solar energy, phytoplankton need inorganic substances for their development. Live organisms are composed of up to 60 chemical elements, but 90–95% of their biomass is composed of six main elements: carbon, oxygen, hydrogen, nitrogen, phosphorus and silicon. Carbon, nitrogen, phosphorus and silicon compounds, necessary for the vital activity of all organisms, are now called "*biogenic elements*" or "*nutrients*" [67].

The ocean is also a prospective source of mineral resources. The amount of prospected minerals in the ocean grows steadily. Thus, in the 1940s and 1950s the total reserves of oil and gas discovered in the sea bottom were estimated at about 55 billion tons. In 1966 this value was 207 billion tons, in 1971, 300 billion tons, and in 1975, 400 billion tons. In the 1990s, such oil and gas reserves are estimated at 500 billion tons. Meanwhile, in 1954, 0.8 million tons of liquid and gaseous hydrocarbons were produced from the ocean bottom, 0.12% of their annual global production. In 1960, this value was 9.35 million tons (0.9%), in 1970, 365.5 million tons (16.1%), and in 1981, 956 million tons (21%). Oil and gas constitute more than 90% of all the raw materials produced from the ocean at present. Over 80 states produce oil and natural gas from the continental shelf. According to expert estimates [49], marine resources of ilmenite, rutile, tantalite, magnesite, gold, and platynite, diamonds are comparable to the reserves of these minerals beneath the land. The reserves of construction materials (sand, gravel, shell rock, limestone) are inexhaustible. In addition to discovered underwater deposits of minerals, sea water contains huge amounts of inorganic salts of rare metals (uranium, lithium, etc.). Each cubic kilometer of sea water contains about 37.5 tons of dissolved inorganic substances.

At present, in addition to oil and gas, the ocean provides 90% of the global production of bromine, 60% of magnesium, 70% of sodium chloride, and 50% of zirconium and rutile. Appreciable deposits of tin, gold and diamonds are being discovered every year. Production of bauxites, phosphorites, aluminosilicates and various construction materials grows steadily [62].

Over 10 years ago, iron–manganese concretions were discovered on the ocean bottom. They contain up to one-third of all the elements of the periodic table, and it proved expedient to mine these concretions to produce important metals such as cobalt, nickel, copper, magnesium, vanadium, molybdenum and, of course, iron and manganese. Every year, more and more new concretions are found on the sea bottom [2].

In the forthcoming decade, mineral raw material production from the bottom of deep (4–5 km) ocean areas will become feasible. At present, intense prospective work is being carried out; complicated instruments are being designed and manufactured to extract mineral resources from beneath the sea bottom and to take them on-board sea vessels.

Ocean waves, tides, thermal gradients, sea currents, etc. possess tremendous power potential. According to expert estimates, the tidal energy of the English Channel alone could cover peak demands for electric power in the whole of Europe. The ocean is also an inexhaustible source of heavy water for nuclear reactors.

It should be noted that humankind, throughout history, has always been attracted to the ocean. At present, half of all the largest cities in the world, with a population of 1 million people or more, are situated in the coastal zone [82]. The degree of urbanization of coastal areas increases every year. If the situation does not change in the near future and tremendous capital investments are not made in domestic and industrial waste water treatment, about 90% of all effluents will be discharged into the ocean without any treatment [80].

One of the most important problems facing ecologonomics today is the creation of favorable conditions for the formation of marine natural productive forces, the ocean ecosystem being the main component of these forces.

The solution of ecological and economic problems of marine natural resources management is connected to the use of the natural restoration capacity of the ocean ecosystem. Tendencies towards integration have always been inherent in the marine economy. At present, the ecological factor, too, is beginning to act as a catalyst to marine economy socialization, promoting the formation of certain holistic socio-ecologonomic units, facilitating the self-regulation and self-correction of marine ecosystems involved in economic development.

The requirement of environmental expediency, as applied to marine natural resources management, is the causative factor, transforming economic relations both within the marine economies of individual countries and at the international level [83].

A system of marine economic relations, determined by the peculiarities of the marine ecosystems involved in the productive forces of the marine economy, reflects the dialectics of the interaction between the marine economy and ecology.

Economic relations that result in the destruction of marine ecosystems set natural limits for their own further development. Moreover, such relations endanger the existence of the marine economy itself.

Striving to obtaining advantages today leads to interbranch and international conflicts, which are not in any way inherent in the nature of the ocean ecosystem, and which necessitate coordination in the domain of marine natural resources production and use.

Many branches of the marine economy (e.g. fishing industry) appeared long ago, when extensive types of economic development prevailed, based on the assumption of the inexhaustibility of marine natural resources. Such economic relations hinder the necessary ecologization of the marine economy, since they do not stimulate an economical approach to the marine environment and its resources. Ecological trouble in inland seas and numerous river basins testifies to this.

The further development of the natural productive forces of the marine economy is impossible without establishing adequate production relations for marine natural resources management. Preservation of ecological balance (i.e. self-regulation and self-correction of the ocean ecosystem) is directly connected to an increase in the efficiency of development of marine natural productive forces.

Ecologonomic principles of marine natural resources management are of an objective character. They do not depend on those in charge of natural resources management. However, when implementing these principles in their economic activity in the ocean, such managers should be aware of their economic advantages. These advantages should guarantee the implementation of all the ecologonomic principles.

The first ecologonomic principle of marine natural resources management is that of *preservation of natural cycles of substance turnover in the ocean ecosystem.*

Substance turnover and energy transformation are the basis for the stability and dynamic balance of the marine environment. The natural sciences give us an idea of such turnover. Natural substances extracted from the ocean and transformed into particular products should be, eventually, returned to the ocean ecosystem. But are they really returned there? This is a difficult question. We assume that these substances *are* returned to the ocean, but in a modified form. If such a returned product is close to the one extracted (natural or similar to natural), it does not cause damage to the marine environment and is assimilated by the ecosystem. However, in reality, substances returned to the ocean at the end of the production cycle can hardly be called "natural" or "similar to natural", and this can lead to unpredictable consequences. For this reason, if we cannot correctly understand the dependence, not only of the marine economy, but of society as a whole, on the functioning of the ocean ecosystem, if we cannot set priorities in marine natural resources production and follow these correctly, and if we are unable to establish rational ecological and economic relations with the ocean, then the resulting contamination and destruction of the ocean ecosystem will be just a matter of time.

Marine environment protection against pollution envisages a decrease in the negative impact of economic activities (both in the ocean and in coastal areas) on the marine environment. Note that the operation of various industrial enterprises on the coast is not necessarily directly related to marine natural resources management. A decrease in the negative effect of individual enterprises can be achieved by reducing the discharge of pollutants, not only into bodies of water, but also into the atmosphere and lithosphere.

All the components of the process of marine natural resources management are interrelated and affect each other directly. That is why the aim of the principle of natural substance turnover preservation is to ensure the orientation of economic activities to closed-cycle or wasteless technologies in all branches of industry and agriculture. These economic activities should form a set of successive production stages, connected with each other by natural substance transformation. What does this mean? We know about the development of wasteless technologies. However, the ecologonomic system of marine natural resources management should not only stimulate the elaboration of environmentally safe technologies, but also improve the technological links between aspects of the marine economy which are included in the ecosystem of an individual sea or basin. Going back to the problems of elaboration, creation and introduction of such technologies, we are looking at the ocean with hope: the future of the ocean depends on the successful development and application of these new technologies.

The second principle is the *principle of preservation of the ocean's spatial integrity.* It is connected with the renewal of the ocean ecosystem. Such renewal envisages the renewal of all the animate resources (animal and vegetable) included in the ecosystem of an individual sea basin. The violation of functional relations between the resources in question will destroy the ecosystem's integrity in the given sea basin, leading to disturbance of the natural base of the marine economy.

At present, with the increasing scale and rates of economic development of the ocean and coastal areas and intensifying human impact on nature, the problem of preserving the marine natural environment is acquiring ever greater prominence. This is the basis for the third ecologonomic principles of marine natural resources management – the *principle of preservation of marine environment quality.* This is relevant to all the problems relating to protection, restoration and rational use of marine natural resources. This principle should be implemented taking into account all the relevant relationships, among which the interaction between the production sphere and the marine environment is the most important. The result of such interaction manifests itself in two ways. On the one hand, marine environment quality changes. On the other hand, variations in the scale and direction of economic activity, depending on changes in environmental conditions, become possible. Thus, modified parameters of the marine environment begin to influence the production sphere directly. Such influence can also be indirect – through allied branches of industry.

We understand *marine environment quality* to be the totality of the parameters that determine its suitability for use. This definition reflects the ability of the marine environment to meet the economic demands of society. We can distinguish the normative (standard) quality of the marine environment as the state when it meets, completely, the requirements of economic development. At the same time, the marine environment itself acts as a natural productive force. Evaluation of its quality requires estimation of its physicochemical and hydrodynamic parameters, and evaluation of its properties as a habitat for plants, animals and people.

Observance of the principle of marine environment quality preservation involves solving problems of the conservation and renewal of natural resources.

We can put forward the following basic demands to sectors of the economy which produce and use marine natural resources as raw materials for their production processes:

- balanced rates of economic development of different sectors and their compliance with marine environment quality parameters, ensuring the continuing use and renewal of natural resources;
- assessment of the multivariance in development trends of individual sectors, both separately and in their optimum combination;
- assessment of the effect of integrity achieved through coordinating the various sectors within a single ecological–economic system.

The fourth principle – *the phase principle* – takes into account the sequence of natural resources production and use, and the potential for preserving the balance of the marine environment.

The first phase is the one during which the operation of individual branches of the marine economy do not disturb the balanced state of the marine environment, and the latter can stand external loads without any external assistance. The financial expenses for natural environment conservation and renewal of natural resources are fairly small.

The second phase is the one during which the maintenance of the marine environment's balanced state requires considerable effort, and radical changes in the technology of marine natural resources production are required. The costs of environment conservation measures are high.

Finally, the third phase commences when the self-restoration capacity of the environment becomes, actually, exhausted, and tremendous capital investments are needed to return the environment to its original balanced state.

All ecological patterns of marine economic activity, and the spatial organization of the marine economy are connected to the adaptation to temporal variations in the ocean ecosystem. However, if the temporal and spatial distribution of marine economic activity affect the state of the marine environment, then the latter, in turn, impacts on the marine economy. This can either promote the increased efficiency of the marine economy, or bring to naught all efforts if the work of marine economy development and the patterns of the marine ecosystem's functioning are in conflict with each other.

The factor of time is inherent in all economic relations. However, the ecologonomic approach to marine natural resources management requires accounting for economic and ecological (i.e. natural) fundamentals of economic activity, both being subject to temporal variations. Carefully planned redistribution of material, labor and financial resources in the marine economy is essential to ensure their optimum use under the conditions of constant change in the ocean ecosystem.

Processes related to the state of the marine environment are determined by both short-term and long-term factors, and so the details of these processes must be taken into account not only for the present, but also for the distant future. It is necessary to determine the effects of long-term and short-term factors on the economic efficiency of marine natural resources management at present and in the future, taking into account the necessary increase in capital investment for marine environment conservation.

Wise marine natural resources development requires a purposeful ecologically substantiated formation of an ecologonomic system, which would take into account the consequences of activities in all branches of the marine economy, both in the present and in the future.

Ecologonomic forecasting should be based mainly on the evaluation of the consequences of predictable changes in the ocean ecosystem. In this respect, the ecological forecasts must be ahead of economic planning. In other words, in order to predict the development of the marine economy, we must take into account, not only the results of economic activities, but also the environmental consequences of those activities. This is possible only when an ecological forecast is made for 10–20 years or more ahead. If the increase in the economic efficiency of marine natural resources management does not establish ecological (and, therefore, economic) responsibility among the managers of the marine economy, then the time will come when it will be necessary to determine who is responsible for the profitable but environmentally dangerous results of such economic activities.

Therefore, the fifth (and the last) ecologonomic principle – that of *optimum character of marine natural resources management for the distant future* – becomes very important. It should be borne in mind that all the negative ecological consequences of marine economic development are irreversible. At present, the self-correction capacity of the marine environment can suppress the destructive effects of human-induced pollution and economic activity in general. But this capability of the marine environment has its limits.

In order to realize in practice the earlier-mentioned ecologonomic principles of marine natural resources management, a higher level of marine economic organization is required, as well as a properly developed scientific and technological base. Our scientific duty is to accumulate knowledge, without which not only the further development of the marine economy but the socio-economic progress of the whole of society is at stake.

2.2. Formation of Ecologonomic Systems

An ecologonomic approach to marine natural resources management should bring about an entirely new attitude to the marine environment's potential. It should overcome the stereotypes that exist based on the assumed inexhaustibility of marine natural resources and the great capacity of the marine ecosystem to neutralize the harmful effects of the wastes of the entire world economy.

We understand *efficient marine natural resources management* to be such a system of activities which ensures economic exploitation of marine natural resources and provides conditions favorable for their renewal, taking into account the present and future interests of the marine economy.

Two interrelated spheres of human activity may be examined when considering the ecologonomic system of the ocean:

(1) efficient production of marine natural resources;

(2) efficient protection of the marine environment against pollution (Figure 2.1).

Efficient production of marine natural resources, in turn, has two elements:

- efficient production of renewable resources;
- efficient production of non-renewable resources.

The interaction between these two units in Figure 2.1 is a complicated problem, which requires a systems approach for its solution. Thus, efficient production of renewable resources as an independent activity should preserve and enhance the resource potential of the ocean on the basis of:

- efficient utilization of the reserves of developed marine raw material deposits;
- intensification of recovery from the ocean depths;
- reduced losses of marine mineral resources during their production and processing.

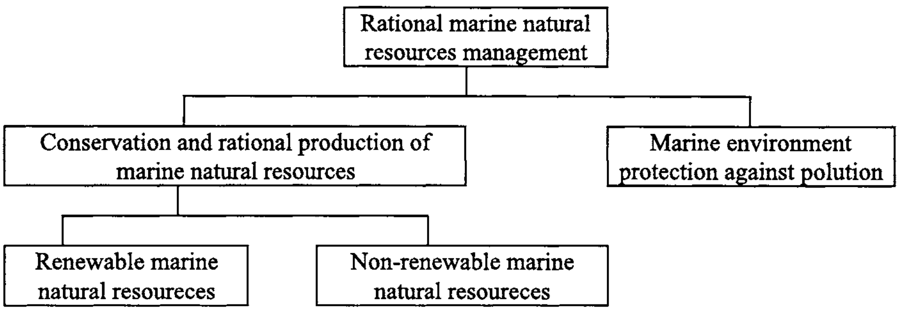

Figure 2.1. Scheme of rational marine natural resources management.

Efficient production of renewable marine natural resources should take into account the fact of their exhaustibility, and should make possible their restoration.

We distinguish ecologonomic systems at two levels: global and regional. The *global ecologonomic system* is the ecosystem of the whole World Ocean, considered in terms of its interrelationships with economic activities located both in the ocean itself and in the coastal areas of the continents.

Regional ecologonomic systems are ecosystems of individual sea basins in terms of their interaction with economic activities located both in the coastal zone and on the continental shelf within a given sea basin (or group of sea basins).

Figure 2.2 presents the mechanism of ecologonomic system functioning as a process of substance and energy circulation in its subsystems.

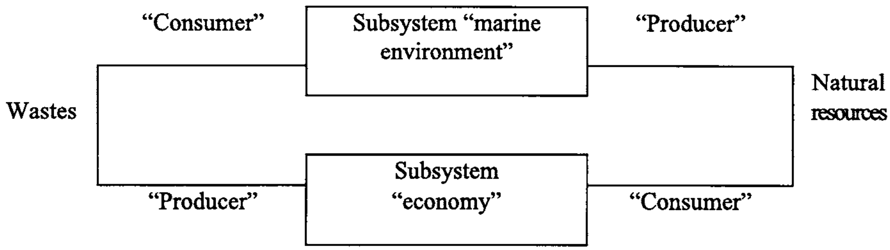

Figure 2.2. A simplified scheme of the interaction between the subsystems "marine environment" and "economy" within the framework of an ecologonomic system.

The subsystem "marine environment" is understood in this case to be a "producer" of various resources, whose "consumer" is the subsystem "economy". In contrast, the subsystem "economy" is a "producer" of wastes, while the subsystem "marine environment" as a natural complex is a "consumer" of these wastes. Thus, the interaction between the subsystems "marine environment" and "economy" and their functioning within a single ecologonomic system are realized in a closed (but not isolated) system of substance and energy turnover, where they are transformed into new forms by the input of human labor. These new forms are destined to meet the social and economic demands of society.

An ecologonomic system can be analyzed not only from the viewpoint of substance and energy circulation between its two subsystems, but also from the viewpoint of the consequences of such circulation for each of the subsystems.

First, let us consider the environmental consequences of human economic activity for the subsystem "marine economy". The ocean is a most important component of the Earth. Through their economic activity, human beings affect the environment (in this case, the marine environment). The degree and consequences of such human impact may vary, manifesting themselves in all kinds of changes, both in the individual components of the environment (hydrosphere, lithosphere, atmosphere) and in the whole natural complex. Let us call such changes *environmental consequences* [84, 85].

Modified natural complexes and their individual components, in turn, affect humans themselves and their activity, i.e. the subsystem "economy". Thus, human-induced changes in the subsystem "marine environment" do not remain neutral towards the subsystem "economy". A certain feedback appears: "economy" begins to affect "marine environment", and the results of such impact will, in the end, have their own effect on "economy".

On the whole, manifestations of negative environmental consequences of natural resources development are typical not only of the World Ocean, but of all the natural complexes of the planet. Note, however, that although modern economic activity has radically changed our planet, these changes are the net effect of local or regional human impacts on natural processes. They have acquired a global character not as a result of changes in planetary-scale natural processes, but due to the fact that these local or regional impacts have spread over vast areas.

In the concept of unity and interrelationship in ecologonomic systems, we must distinguish between notions such as "impacts" and "consequences", although these categories are relative, and one and the same phenomenon can act as both consequence and impact with respect to different objects of analysis. For example, changes in the marine environment or its individual components can be regarded as both "consequences" (of the effect of the subsystem "economy" on the subsystem "marine environment") and "impacts", understood as the "effect" of these "consequences" on human beings and their activity (i.e. the impact of the subsystem "marine environment" on the subsystem "economy").

Figure 2.3 presents a general (base) model. It is of a global character, because all its links are closed within the ecologonomic system of the whole World Ocean. This model, reflecting ideas about and trends in the unity and interdependence of the economy and marine environment, can serve as a basis for identifying and formally describing real ecologonomic systems of various scales and levels, typical of certain types of marine natural complexes, industrial sectors and human living conditions.

While analyzing interactions in the system "marine environment – economy", we must pay special attention to such economic activities involving marine natural resources, processes and phenomena occurring in the marine environment and negative consequences which might arise. Depending on the aim of the research, we can distinguish the following types of economic activities: bioproduction (fishing, fishing for marine invertebrates, alga production); cultivation (artificial cultivation of fish, algae and invertebrates); oil and gas production; mineral resources production; health resorts and recreation; hydroelectric power production; and others.

In general, the mechanism of interaction in the system "marine environment–economy" works as follows. Human economic activity has varying impacts (in both character and intensity) on the components of marine ecosystems. *Components of marine ecosystems* are marine water composition, substrate, flora and fauna. The aforementioned impacts result in various changes occurring both in individual components of marine ecosystems and in the ecosystems as a whole, thus leading to disturbance of the ecological balance. Owing to the fact that each ecosystem is considered to be a "producer", its modified state will be manifested in the deficit of resources it produces. Resource deficit, in turn, will lead to curtailment of economic activity, which will necessitate developing other types of resources and result in greater changes in ecosystems, thus increasing the anthropogenic load on the ecosystems. Through the interaction between individual components within a single ecosystem (vertical connections) and the interaction between similar components of different ecosystems (horizontal connections), these changes spread over the whole World Ocean. Thus, constant reactions, involving ecosystems at all levels, proceed in the World Ocean.

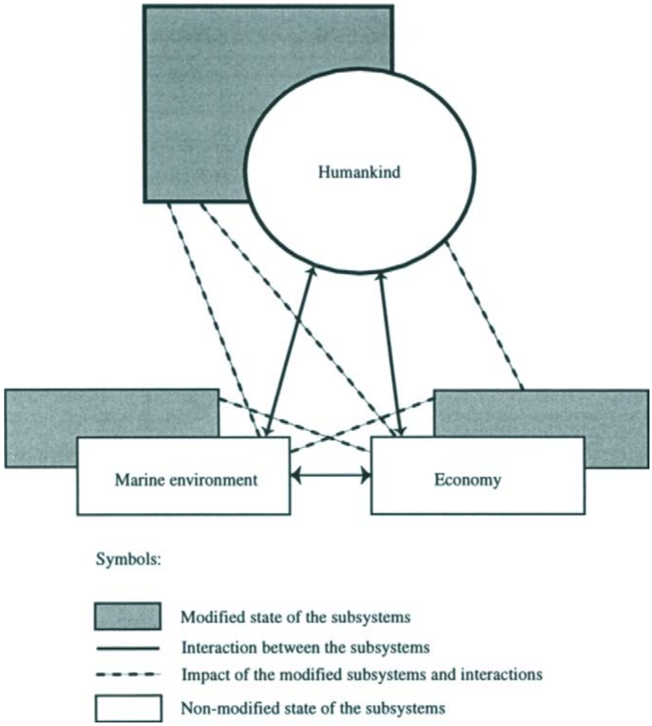

Figure 2.3. Model of the global marine ecologonomic system.

Modified ecosystems, in turn, have their own effect both on individual branches of the marine economy and types of economic activity directly related to marine natural resources management, and on economic development in general. Under such influences, the system "marine environment–economy" acquires a new state, characterized by a decrease in useful production, an increase in the rate of ecosystem destruction, and a deceleration of restoration processes. In this case, because the economy is inertial, the discontinuity between the impact on the environment and the response of the economy to such an impact begins to manifest itself. However, if the economy does not respond to marine environment changes in time, its development will be restricted.

Economic and environmental consequences of the interactions in the system "marine environment–economy" will be analyzed in subsequent chapters.

Ecological–economic examination of various scenarios of coastal region development plays a most important role in forming an ecologonomic system for this region. Such an examination is based on the model of regulation of the natural environment in the region and on methods of economic evaluation of the damage caused by human economic activity to the marine environment. Such an examination should also make use of methods of cartographic analysis, and of existing ecological expertise. The process of ecological–economic examination includes the following stages:

- analysis of a selection of project solutions, including alternative possible locations and technical equipment for the economic objectives under consideration;
- evaluation of the economic results and environmental consequences of the realization of each variant;
- selection of the optimum scenarios for economic development of the region, based on the available economic potential and existing requirements of the marine environment;
- calculation of the possible damage to individual marine ecosystems expected as a result of the implementation of selected variants of regional development;
- formation of a system of priorities for investigating environment conservation measures that might be required following implementation of the selected scenario of the region's development.

Figure 2.4 presents an enlarged block scheme of ecological–economic examination of various scenarios of coastal region development.

The first block of the scheme – data bank organization and the formation of a set of regional development scenarios – will be used for the collection and processing of the input economical, ecological and geographical information concerning the region in question and suggested scenarios for its economic development. Feasibility studies for projects of industrial plant construction, comprehensive programs of economic development of the region, etc. can be used as sources of such input information.

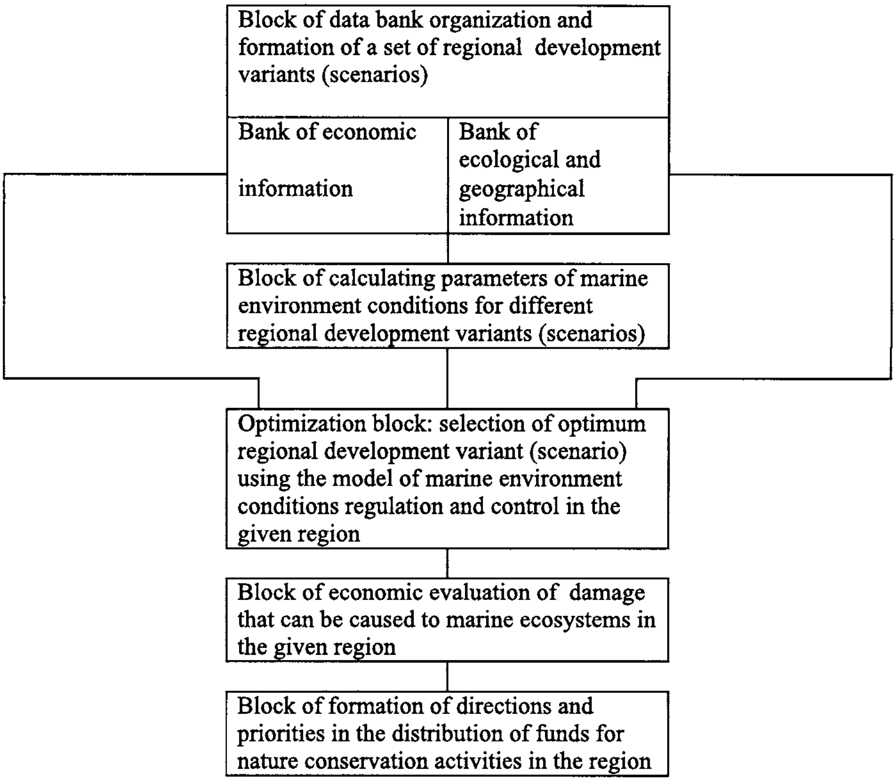

Figure 2.4. Block scheme of the ecological–economic examination of different variants (scenarios) of coastal region development.

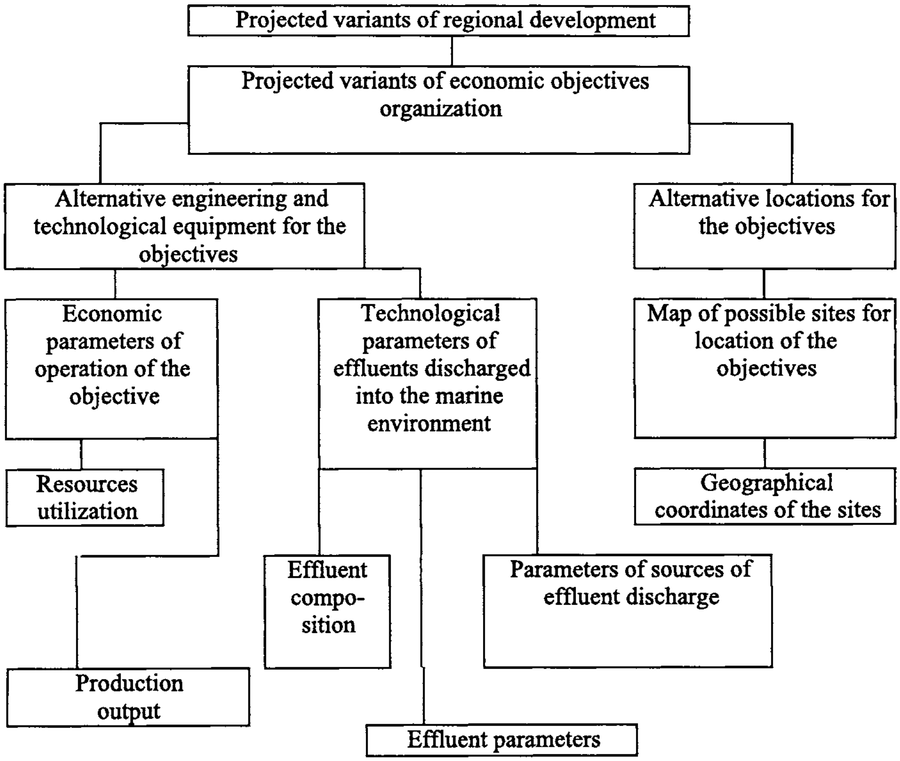

Figure 2.5. Structure of economic information for the first block.

The structure of economic information required for calculations is presented in Figure 2.5. The collection and processing of ecological and geographical information also include the creation of special maps and the composition of a set of physicogeographical data. The collection and processing of ecological and geographical information and the formation of the respective data sets are presented in Figure 2.6.

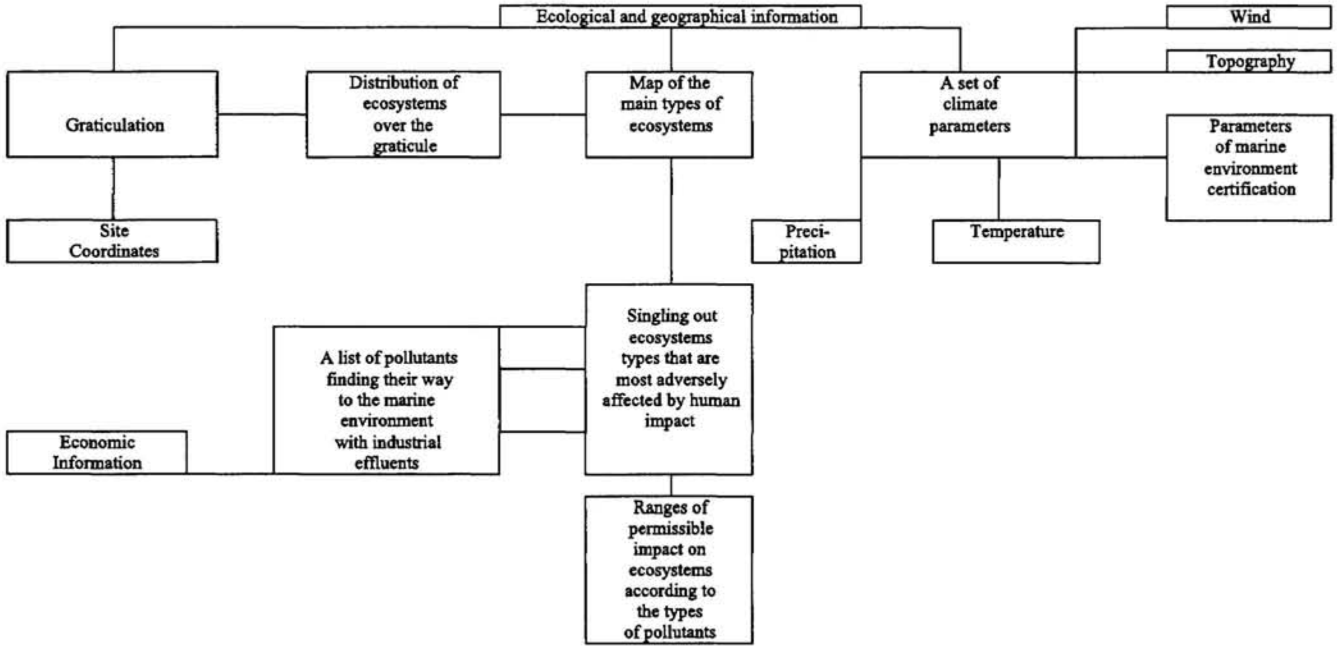

Figure 2.6. Structure of ecological and geographical information for the first block.

In order to understand the chain "human impact – parameters of the marine environment state in the region", it is necessary to evaluate the initial (background) state of the environment in the region, its assimilation capacity and some other characteristics. The chains "human impact – parameters of the marine environment state" relevant to maintaining sustainable economic development of the region and preservation of the balance of its ecosystem can be obtained from a process of calculations associated with the second block of the ecological–economic examination, the *block of calculations of the marine environment state parameters*, implemented according to regional development scenarios. The stage of obtaining such chains is followed by the stage of decision making on the regulation of the character and degree of human impact, which will facilitate "dosing" the load on the marine environment in the third block of our scheme.

As a result of calculations on the basis of the model of the regulation of the marine environment in the region, implemented in the third block of the ecological–economic examination (block of optimization), the optimum scenario for regional development is selected, and then subjected to further careful economic analysis. The mathematics used for this purpose allows us to make important decisions on measures necessary to preserve the environmental balance in the region.

Let us now analyze a general scheme for regulation of the marine environment in each region:

$$\min Z = \sum_j c_j x_j \to \min \tag{2.1}$$

$$\sum_j c_j x_j \geq B_i; \quad i = 1,\ldots,m \tag{2.2}$$

$$\sum_j e_{pj} x_j \leq L_p; \quad p = 1,\ldots,t \tag{2.3}$$

$$\sum_j h_{kj}^r x_j \leq H_k^r; \quad k = 1,\ldots,Q; \quad r = 1,\ldots,R \tag{2.4}$$

$$x_j = \begin{cases} 0 \\ 1 \end{cases} \quad j = 1,\ldots,n \tag{2.5}$$

Here:

x_j is the vector of the intensity of implementation of the projected regional development scenario;

A_{ij} is the specific output of the *i*-th product according to the *j*-th development scenario;

B_i is the production program for the output of the i-th product for the region;

I_{pj} is the specific expenses of the *p*-th type of resources upon the implementation of the *j*-th development scenario;

L_{pj} is the limit for the *p*-th type of resources allocated (or available) in the region;

h_{kj}^{r} is the real load on the ecosystem of the r-th type, caused by the *k*-th pollutant (waste), according to the *j*-th development scenario;

H_{kj}^{r} is the permissible load on the ecosystem of the *r*-th type for the *k*-th pollutant;

C_j is the total reduced cost of implementation of the *j*-th development scenario in the coastal region.

Note that in this setting of the problem of marine environment quality regulation, a group of constraints *r* ensures implementation of the production program for the output of the *i*-th product in the region (i = 1, 2,..., m). A group of constraints (2.4) assigns the regional environmental conditions necessary for the preservation of unchanged structure and quality of the ecosystem. Condition (2.5) shows that for each projected scenario two solutions are possible: it can either be approved (x_j = 1) or rejected (x_j = 0). Dependence (2.1) prompts the selection of a development scenario for the region such that equations (2.2)–(2.5) are observed with simultaneous minimization of the cost of implementation.

According to the theory of dualism in mathematical programming, a particular dual task is assigned to each extreme task. The joint study of these two tasks is the basis for the quantitative analysis of the obtained solution.

In the model of regulating the marine environment quality in the region (Equations (2.1)–(2.5)), the vector of dual estimates is presented as:

$$\chi = (U_j, V_p, Y_k^r) \tag{2.6}$$

where

$$U_j = \mathrm{d}Z/\mathrm{d}B_i; \quad V_p = \mathrm{d}Z/\mathrm{d}L_p; \quad Y_k^r = \mathrm{d}Z/\mathrm{d}H_k^r \tag{2.7}$$

Owing to the fact that the task function of marine environment regulation in the region presents the sum of the reduced costs of implementation of particular regional development scenarios, dual estimates express the relations between these costs and the structure of assigned constraints (production, resource, environmental). Zero values of the estimates will correspond to the conditions not restricting regional development. Maximum absolute values of the dual estimates U_i correspond to the branches of industry ensuring maximum saving of financial resources. Progressive development of such branches in the region will provide the maximum possible decrease in total reduced cost. The maximum positive estimates of resources V_p mean the maximum deficiency of this type of resources. Finally, an increase in the dual estimate of the p-th type of resource means an increase in the efficiency of its use in the region.

Estimates Y_k^r are normative from the viewpoint of relations between economic parameters and marine environment state in the region. Zero values of these estimates correspond to marine ecosystems for which the real load exercised on them does not lead to negative consequences and does not cause damage to them. On the contrary, the maximum values of these estimates correspond to ecosystems for which the anthropogenic load is so high that additional expenses are required for their restoration. An increase in the function Y_k^r denotes an increase in the additional expenses required to reduce the harmful effects of human impact on the ecosystem and to increase the efficiency of capital expenditure on environment protection measures.

Investigation of the stability of the solution obtained allows us to determine the limits of its stability and preservation of dual estimate values. This investigation allows us to determine the quantitative range of changes in the load on individual ecosystems, and hence the reduction in additional expenditure on environment conservation. In particular, such research can help us determine the value of the anthropogenic load on a certain ecosystem that would ensure the reduction of additional expenditure on environment conservation.

Study of the stability limits of the solution obtained and its dual estimates allows us to coordinate the economic and ecological objectives of a coastal region's development within a regional ecologonomic system. Such coordination can be implemented as follows. First, as a result of the analysis of the solution obtained, we identify low-efficiency (requiring considerable capital investment) industries, whose development should be restricted so as to decrease the anthropogenic load on the ecosystem without infringing the economic results (i.e. without any deterioration of the task function (2.1) in the model (2.1)–(2.5)). Second, through investigating the stability of the solution obtained, we can identify reserves of individual ecosystems which will allow further industrial development, thus increasing the anthropogenic load on the ecosystems within the assigned limits and causing no damage to them.

In conclusion, the basis for efficient marine natural resources management is the creation of ecologonomic systems on both global and regional levels.

2.3. Management of Ecologonomic Systems

Ocean development will be optimum only when all the industries interacting with the sea operate in such a way that the state of the marine environment will remain within certain limits, allowing for the further production, utilization and natural renewal of all its resources. It is only under such conditions that the marine environment will be able to act as a stable productive force. Therefore, ocean development is impossible without economic management that balances the rates of development of all branches of the marine economy with resources production and renewal, and preservation of the quality of the marine environment.

We suggest analyzing the existing ecologonomic systems in four main directions.

The first direction of research is systems analysis of the overall hierarchy of processes occurring in ecologonomic systems. Within this framework, the character, forms and scale of present and past interactions and interdependencies in systems of the type "ecosystem–environment–economy" should be investigated. We interpret these systems for the marine environment. Next we determine their balanced state, paying special attention to the problem of balanced and sustained development of all their components.

The second direction is the elaboration of scientific fundamentals for ecologonomic systems management. Within this framework, based on our knowledge of objective laws of ecologonomic systems development and the limits of possible impact on them, we should elaborate a general methodology and specific techniques for such management. At this stage it is appropriate to create a set of estimation criteria and parameters of the efficiency of an ecologonomic system's functioning.

The third direction is the evaluation of marine natural resources, primarily the resources of marine ecosystems. It is at this stage that we develop mechanisms for optimizing marine natural resources management.

The fourth direction is the development of a body of relevant mathematics, without which it is impossible to solve problems related to the forecasting of ecologonomic systems development.

The first steps in elaborating the theoretical fundamentals of ecologonomics date back to the late 1970s, and since then *ecologonomic systems management* has become one of the most acute problems that this new science faces. As with any other form of management, the management of ecologonomic systems includes three elements: the subject of management; means of management; and objectives of management.

As mentioned earlier, any ecologonomic system comprises three subsystems: "ecosystem", "marine environment" and "economy". For this reason, the *subject of management for any ecologonomic system* consists of exactly these three subsystems, considered in terms of their interrelationships.

Ecologonomic systems are extremely complicated. However, we must try to manage them, to the extent at which we affect them today (or will affect them in the future), pursuant to the laws of productive forces development. For example, the biological productivity of the ocean ecosystem is a factor having a certain economic effect. This effect is achieved when we withdraw a certain component of this ecosystem, which has its own economic value. If the withdrawn product (or an appropriate substitute) is not returned to the ocean ecosystem, the latter eventually becomes exhausted, and such exhaustion cannot exist for long without leading to the destruction of the whole ecosystem.

Therefore, the *objective of ecologonomic system management* is to obtain the maximum economic effect from producing and utilizing each type of marine natural resources, envisaging simultaneous preservation of the self-correcting and self-regulating capacity of the system. This can be illustrated by the example of aquatic biological resources: fishing may be allowed only if we leave intact sufficient fish population to preserve their reproductive capacity. Another objective of management, not necessarily directly related to marine natural resources production and use, is maintaining marine environment quality within certain limits.

Ecologonomics also deals with problems of financing scientific and technological progress in the sphere of natural resources management – aimed at its optimization.

Maintaining necessary conditions for natural resources renewal is also one of the objectives of ecologonomic systems management. We must try to compare (such comparison should be both precise and unbiased) the current effects of the production and use of each type of resources with the effects that might be obtained from the production and use of the same type of resources in the future. The maximum economic benefit from managing ecologonomic systems can be achieved only within the framework of a systems approach to the realization of both economic and environment conservation measures.

The main *means of ecologonomic systems management* are:

- economic evaluation of marine natural resources;
- estimation of damage and the cost of compensation for it;
- estimation of the profit from marine natural resources production and use at a given stage of human social development – in order to determine the efficiency of such production and use of the given type of resources at the present level of human social development.

The unification of ecology and economy allows us to control various links in the system "ecosystem–marine environment–economics", based on our knowledge of the laws governing the functioning of such systems. This unification, in turn, is based on the *category of marine environment quality.*

Note that here and below, pursuant to our concept of marine ecologonomics (see section 1.3), we shall analyze ecologonomic systems of the type "ecosystem–marine environment–economy", which differs, to a certain extent, from the system "marine environment–economy", discussed in section 2.2. The latter, in our opinion, is somewhat simplified, because in reality all the processes of interaction between ecology and economy occur within the limits of the marine environment, which is not merely a background against which such interaction takes place, but an important participant in these processes.

Energetic processes occurring at all levels of the ocean are closely interrelated, and an impact exercised on one of them can lead to disturbance in the whole chain of interactions. For example, a decrease in river runoff leads to changes in the salt composition of water and the biological characteristics of certain sea basins, whereas the withdrawal of any type of biological resources from the food chain does not affect the hydrological regime of water bodies in any way.

It is a well-known fact that consequences of any economic impact manifest themselves only after some time, because of the inertia of the marine environment. This means that any disturbance (impulse or heat flux, pollutant inflow, changes in living organisms, etc.) causes a response in the marine environment (a kind of a "feedback"), determined by both the original ("background") state of the environment and the intensity of the disturbance itself. If the intensity of human impact on any parameter of the environment is much less than the amplitude of natural variations in the same parameter, then this effect will be localized and, after some time, neutralized. If the intensity of anthropogenic impact and the amplitude of natural fluctuations in physical, chemical or biological parameters of the marine environment are comparable, then new stable cycles resistant to such disturbance will appear, and the system will preserve its balanced state. However, if the intensity of the disturbing impact greatly exceeds the amplitude of the earlier-mentioned natural variations, then environmental changes will become irreversible, and the restoration of the original (background) environmental parameters by natural means will be impossible.

The effect of the economy on the marine environment can be represented as a three-staged process.

In the first stage, the impact of the production sphere is neutralized by the self-restoration capacity of the marine environment. Management of marine ecosystems' resources is carried out according to an assumption of their inexhaustibility.

The second stage commences when a certain assigned level of marine environment quality is maintained, due both to its self-restoration capacity and to the implementation of nature conservation measures. In this case, capital investment is necessary to preserve both the standard quality of the marine environment and the self-restoration capacity of the marine ecosystem within the given environment.

The third stage is characterized by the following situation: the ecosystem is no longer capable of self-restoration, and the required standard of the marine environment is maintained only with the help of special measures to protect it against harmful consequences of industrial development.

Let us consider a typical example to illustrate the notion of marine environment quality. If any part of the ocean is regularly contaminated with oil and oil products, marine environment quality will be modified not only by direct effects of the pollution, manifest in changes in certain parameters of the sea water (heat balance disturbances, changes in microflora composition, etc.), but also by variations in the near-water air column (decrease in oxygen release) and adjacent land areas (pollution of beaches, etc.). Similarly, wave energy redistribution and changes in bottom sediment transport trajectory resulting from hydrotechnical construction, along with some other consequences, can be considered to be *variations in the parameters of marine environment quality.* Thus, when evaluating marine environment quality, we must take into account both the dynamics of the environment itself and the potential for using it as a productive force. In such cases, a formalized description (i.e. one in which marine environment quality (state) is represented in terms of a set of independent physicochemical parameters, which we call *parameters of the state*) will be appropriate. Let us denote them as E_1, E_2,..., E_n. All these values are subject to both temporal and spatial variations.

Let us now analyze each of these parameters and the dynamics of their variation. The total of these parameters forms a certain area G of an n-dimensional Euclidean space. This area G is called the *area of the states.* In this area, each point has its own corresponding set of numbers, which can be interpreted as the vector

$$\Delta\vec{S} \quad (E_1, E_2, \ldots, E_n)$$

having n components, and identified with the state of the environment.

Let us assume that, as a result of human economic activity, certain components of this state change. Then vector $\Delta\vec{S}$ (2.8) will change too. The difference between the new vector, corresponding to this new state, and the initial vector can be determined as:

$$\Delta\vec{S} = \vec{S} - \vec{S}_{\text{init}} \tag{2.8}$$

This difference reflects changes in the state of the environment. In order to evaluate these changes, it is necessary to express the cost of environment quality changes, in monetary terms, that will allow us to present the cost of damage caused to the environment, or of environment improvement resulting from nature conservation activity.

A formalized description of the marine environment's state allows us to evaluate its quality. For this purpose, let us divide the area of the states G into subareas, to which we shall assign certain qualitative estimates that depend on the subarea to which the above-mentioned vector belongs.

Environment quality is a relative notion, specified by various parameters. In the case under review, environment quality is determined by the ecological requirements of the normally functioning ecosystem. That is why, out of the total parameters of the state $\{E_i\}$ we can single out a set of subparameters $\{E_{ij}\}$, determined by the aforesaid conditions.

According to J. Forrester [86], any dynamic system can be presented as a system of levels (reservoirs), connected with each other by fluxes (tubes). The intensity of fluxes, i.e. the speed of movement of matter, energy and information, is regulated by "flux rates" ("valves"). The regulation rules follow either from the laws of functioning of the ecosystem itself ("implicit solution functions"), or from the laws governing the system externally ("explicit solution functions"). Such presentation of a dynamic system allows us to describe the relations between the concrete marine ecosystem in question and the ecosystem of the ocean as a whole.

In the opinion of Forrester, an *ecosystem* is any system including all the living organisms in the given area and interacting with the physical environment in a manner allowing the energy flux to create a clear-cut trophic structure, species diversity and substance turnover (i.e. substance circulation between the abiotic and biotic parts of this system). An ecosystem model corresponding to the above definition should specify the substance turnover in the system and the energy flux through its biotic component.

Let us analyze a very simple ecosystem (Figure 2.7), comprising the following levels:

(1) *MB* – mass of biogenic elements;

(2) *P* – producers;

(3) *R* – reducers;

(4) *D* – detritus and dissolved organic matter;

(5) *C* – consumers (zooplankton, zoobenthos, nekton);

(6) *M* – mass of the respective level;

(7) *E* – energy of the respective level.

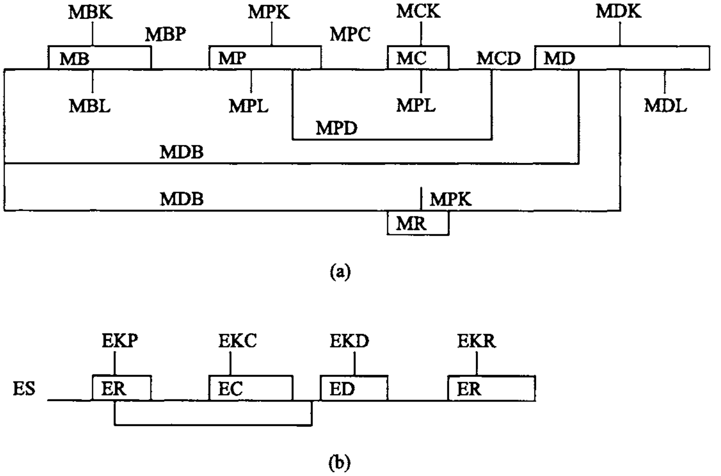

Figure 2.7. Substance and energy fluxes in the ecosystems: (a) substance fluxes; (b) energy fluxes.

As can be seen from Figure 2.7, the levels are connected to each other by substance (a) and energy (b) fluxes, whose intensity is characterized by the rate of mass or energy flow from one level to another. For example, *MBP* is the rate of biogenic elements' consumption by producers, *EPC* is the rate of energy consumption by producers and consumers, and fluxes *ES* and *EJK* (here *J* stands for symbols *P*, *C*, *D* or *R*) correspond to the input of solar energy to the given trophic level and the consumption of this energy by the living organisms at this level. Values E_i and M_i are connected to each other by the ratio:

$$E_i \cong (16.7\alpha + 37.7\beta + 15.7\gamma)M_i \tag{2.9}$$

where

α, β and γ are the proteins, lipids and carbohydrates, respectively, in M_i.

Here we shall not analyze any laws regulating the rates of fluxes between levels E_i and M_i. Instead, let us examine the main differences between substance turnover in the ecosystem (Figure 2.7(a)) and energy flux through the same ecosystem (Figure 2.7(b)). Substance flow through the ecosystem is closed, and within this "closed loop", substance transportation occurs from one level to another. Therefore, at any moment in time, the total amount of substances in the ecosystem is constant:

$$\sum_i M_i = \text{const.} \tag{2.10}$$

where the total substance flux through the system for a characteristic averaging time is zero:

$$\sum_{i \neq j} \sum_i M_{ij} = 0 \tag{2.10'}$$

On the contrary, the energy flux through the ecosystem is enhanced.

According to the first law of thermodynamics, energy inflow to each level is neutralized by its outflow, and energy transport is accompanied by its dissipation into a form inaccessible for utilization at subsequent levels. According to the second law of thermodynamics, the total flux through the system can be presented as:

$$\sum_{i \neq j} \sum_j E + \sum_i EK = ES \tag{2.11}$$

Thus, equations (2.10) and (2.10′) represent the law of mass preservation in the ecosystem, whereas equation (2.11) represents the law of preservation of the energy flux passing through the system at any moment in time.

Withdrawal of certain populations from the marine ecosystem results in the appearance of additional fluxes in this ecosystem, leading to decreases in E_i and M_i. Because, according to equation (2.9), the dependence between E_i and M_i is unequivocal, economic activity affects the values of E_i and M_i.

Let us now represent the effect of human economic activity on the ecosystem as an additional energy flux *ECH* going out of the ecosystem. In this case, equation (2.11) may be expressed as:

$$\sum_{i=j}\sum_{j} E^{\bullet}_{ij} + \sum_{i} E^{\bullet}_{i} K + ECH = ES \qquad (2.12)$$

The appearance of an additional energy flux modifies all the other ones, denoted as $E^{\bullet}_{ij}$ and $E^{\bullet}_{i}K$ in equation (2.12). In accordance with the concept of homeostasis, we proceed from the assumption that the ecosystem can withstand an anthropogenic load *ECH*, varying within the limits $0 < ECH \le ECH_m$, due to restructuring of its levels $E_i - E^{\bullet}_{ij(k)}$ and fluxes $E_{ij} - E^{\bullet}_{ij(k)}$, where $E^{\bullet}_{ij(k)}$ is the critical value of levels and fluxes. Exceeding this critical value can result in disturbance of the homeostasis and self-regulation mechanisms in the ecosystem, which can lead to the latter's degradation.

Therefore, the *ECH* value determined, in most cases, by the expert method is usually adopted as the estimated value of ecosystem biomass, whereas the difference $ECH_m - ECH$ is regarded as the value of additional resources that can be withdrawn from the ecosystem at present and in the near future.

On the other hand, the impact of economic activity on the ecosystem can be presented as an additional mass flux *MCH* going out of the system. In this case,

$$\sum_{ij} M_{ij} = -MCH \qquad (2.13)$$

It follows from equation (2.13) that the affected mass fluxes in the ecosystem will diminish with time, leading to a decrease in the overall mass of substances in the ecosystem.

Marine ecosystem analysis from the viewpoint of mass and energy fluxes demonstrates the danger of human impacts and the necessity for a scientifically substantiated approach to the use of such ecosystems as sources of biological resources. This conclusion is of central importance for ecologonomic systems management.

Simulation modeling can be helpful in the management of ecologonomic systems. Today, there are numerous examples of the application of simulation models for studying complicated ecological and economic systems. This is due to the fact that simulation modeling does not require a strictly formalized description of the system – it is sufficient to know the general algorithm of its functioning and the interaction between its elements. This algorithm should later become the basis for creating a special computer program.

With such an approach to the management of ecologonomic systems, it is necessary to use the most realistic assumptions in the analysis, because simulation models are usually developed to find answers to concrete questions pertaining to decision making in systems management. It is also important to represent fully the peculiarities of a real ecologonomic system and the relations between its components in the simulation model. Such a model usually has a block (modular) structure, allowing easy correction, taking account of newly obtained information.

Developing a simulation model of an ecologonomic system is a three-staged process, including:

(1) word description of the ecologonomic system, its boundaries and the objectives of ecologonomic system management which the model is designed to achieve;

(2) exact setting of a concrete management task, selection of variables and determination of the dependence between them;

(3) creation of an algorithm of ecologonomic system functioning, aimed at subsequent development of a special computer program.

A *word description of the ecologonomic system* is a description of available information about the system. At this stage, internal and external factors, relevant values, and relations between them (that will be taken into account in the model) are specified.

At the stage of *exact setting of a concrete management task*, numerical values are assigned to the parameters selected for use in the model. Here it is necessary to determine the degree of detail in these parameters. The largest and most important part of the work at this stage consists of obtaining the *evolution laws* of the ecologonomic system under analysis, i.e. quantitative description of the relations between the values, which have been previously described in words. At this stage, work is hampered by the lack of information about these relations, and the absence of a common methodology for their quantitative determination.

Simulation modeling is based on:

(1) Scientific patterns of relations between the values, established experimentally or empirically by particular sciences.

(2) Statistical data and methods of mathematical statistics (regression and dispersion analysis, etc.). The use of mathematical statistics for establishing relations between the variables should be strictly substantiated. Frequently, statistical data are the only information on either the behavior of the ecologonomic system in the past or the behavior of other systems, about which we have certain grounds to assume that patterns typical for them are applicable to those in the ecosystem under review.

(3) Certain qualitative notions. Unfortunately, very frequently, neither the necessary statistic data nor reliably established patterns are available for ecologonomic systems management. In such cases, various intuitive considerations (such as similarities in statistical data) about the impact of particular values on other values may be helpful.

(4) Compared to the two previous stages, the stage of creating the algorithm of ecologonomic system functioning is not a very complicated problem. The algorithm becomes the basis for the development of a special computer program.

To develop simulation models for the management of ecologonomic systems, the method of systems dynamics, developed by Forrester [86], considered earlier, can also be used.

In our opinion, at present, ecologonomic systems management can be formalized at a regional level. However, it is hardly expedient to try to formalize the management problems in the form of a large task of mathematical programming. This is because of difficulties in solving multidimensional extreme tasks, and the impossibility of selecting a single criterion for ecologonomic system optimization. However, the main difficulty is the selection of constraints for this task, which is no less important then the selection of the optimum solution. A properly selected (and, what is more important, complete) set of constraints for the task of regional ecologonomic system management restricts the permissible solution area, so that the problem of establishing the optimization criterion becomes less important than might have been assumed initially. Therefore, the main aim of ecologonomic systems management at the regional level should be the determination of restrictions (e.g. *MPC*) that should be taken into consideration when planning economic activity in any coastal region.

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Chapter 3

ECOLOGICAL AND ECONOMIC CONSEQUENCES OF MARINE ENVIRONMENT CONTAMINATION

3.1. Classification of Marine Environment Pollutants

The use of the marine environment as a receptacle for industrial, agricultural and domestic waste, whose amount is constantly growing, is of primary importance for human existence on the Earth. Traditionally, *environment contamination* is understood as undesirable changes in the environment's physical, chemical or biological properties that may, at present or in the future, have a negative effect on ecosystems, and on production processes and the condition of natural resources.

The United Nations Organization adopted a definition that introduces into the notion of *marine environment contamination* the input of substances and energy that cause damage to marine natural resources, human health and economic activity in the sea (including fishing), and reduce the potential for using properties of the marine environment for recreation and other purposes. Such a definition implies not only environment contamination with toxic substances, but also so-called "thermal pollution", as well as the effects of pathogenic microorganisms and some other forms of anthropogenic impact on the environment [87].

The ocean has the ability to dilute and purify the greater part of the wastes coming into it, thus maintaining the dynamic balance of its ecosystems without any human involvement. This capability is explained by the gigantic size of the ocean, the huge volume of its water, and the enormous scale of the physical, chemical and biological processes occurring in it (including transport and precipitation of pollutants, and biological self-purification, which ensure the removal of pollutants from sea water). Such processes are most intense in coastal waters, enriched in oxygen and heated by the sun. Here the greatest species diversity and bioproductivity are observed [52].

However, boundary layers contacting the atmosphere play the most important role in the self-purification of the ocean, irrespective of the fact that they occupy only 2–3% of its volume. In such layers organic matter oxidation occurs at comparatively high rates. The bulk of the ocean is inactive in the transformation of organic pollutants.

For the last two or three decades, the scale of marine environment contamination has become comparable with the magnitude of the ocean's assimilation capacity [88].To a first approximation, we can single out two main channels of pollutant input into the marine environment (Figure 3.1).

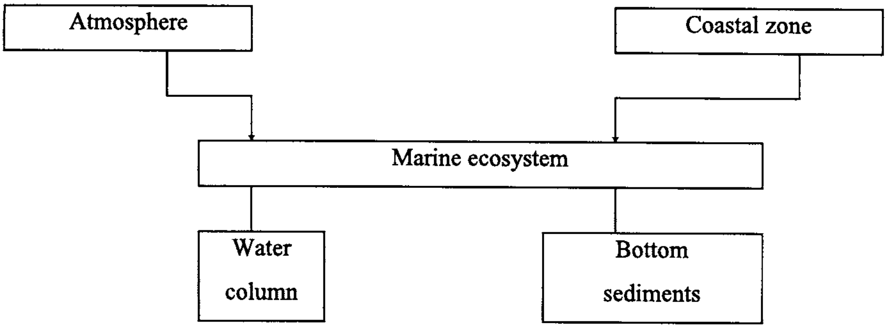

Figure 3.1. Pollutant input into the marine environment.

Pollutant input from the atmosphere via precipitation is related to the formation of an atmospheric reservoir of technogenic pollutants, i.e. with the transfer of some substances from the land surface to the air, their subsequent redistribution in the air and transportation onto the ocean surface via atmospheric precipitation. About 50% of all metals, including mercury and lead compounds, find their way into the marine environment via atmospheric transportation, as do other dangerous substances such as polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), DDT, dichlorethane, freons, etc. The amount of pollutants coming into the ocean from the atmosphere is comparable to the amount of pollutants entering it from river flow [88].

Today, scientists try to identify in the ocean an independent microecosystem at the air–water interface and study its properties. This microecosystem has been found to play a very important role in the circulation process of gaseous, liquid and solid substances between the ocean and atmosphere, and to serve as a habitat for a specific organism community known as nekton. On the surface of the sea water, and in the near-water air layer, increased concentrations of pollutants are detected, which can be redistributed in the surface biota, accumulate in organic clots and cohere with suspended particles involved in biological cycles.

Another channel of pollutant input into the marine environment is the export of certain substances in rivers, which in the long run can create critical situations. The shelf and estuary zones, being the most productive parts of the ocean ecosystem, are subject to most intense river-borne contamination.

Pollutants finding their way to the continental shelf are redistributed here and then transported to the open sea. Large-scale water circulation plays the most important role in these processes.

However, most pollutants are precipitated on the sea bottom (see Figure 3.1), accumulated in hydrobionts and affect near-shore ecosystems, which are the most important for the economic development of coastal areas. According to the degree of proliferation of pollutants, ocean contamination can be classified as:

- local (enveloping up to 10 km^2 of water area);
- subregional (enveloping an area of up to 100 km^2);
- basin (covering the whole water area of one or several seas in a particular basin, spreading to an area of up to 1000 km^2);
- global (affecting the whole ocean).

A *source of pollution* is a particular source that introduces pollutants, pathogenic microorganisms or additional heat into the marine environment.

According to their place of origin, sources of pollution (see Figure 3.2) can be divided into surface sources (a), originating from human economic activity on the continents, and marine sources (b), resulting from human activity in the sea. Pollutant sources can have constant or temporal existence, and may have a point or non-point action (this classification of pollutant sources is widely available in the scientific literature.)

Various pollutants find their way into the ocean via river flow. Land sources therefore play a very important role in marine environment contamination. Up to 80% of pollutants (100 million tons per year) come to the sea from the continent, and this value is constantly growing.

The main cause of marine environment contamination is the discharge of untreated or insufficiently treated industrial, agricultural and domestic waste water into rivers or directly into seas.

Waste waters are waters disposed of in the environment after being used in human economic activity or everyday life. Pollutants in waste water can be divided into several groups. For example, according to their physical state, pollutants are classified as insoluble, colloid or dissolved. According to their chemical composition, pollutants are mineral or organic.

Mineral (inorganic) pollutants include sand, clay, ore and slag particles, mineral salts, acidic and alkaline solutions, etc. Organic pollutants can be of bacterial, plant or animal origin. Organic pollutants of vegetable origin consist of plant detritus. Organic pollutants of animal origin include physiological excretions of animals and human beings, residues of animal tissues and cells, etc.

(a) TERRESTRIAL SOURCES OF POLLUTION

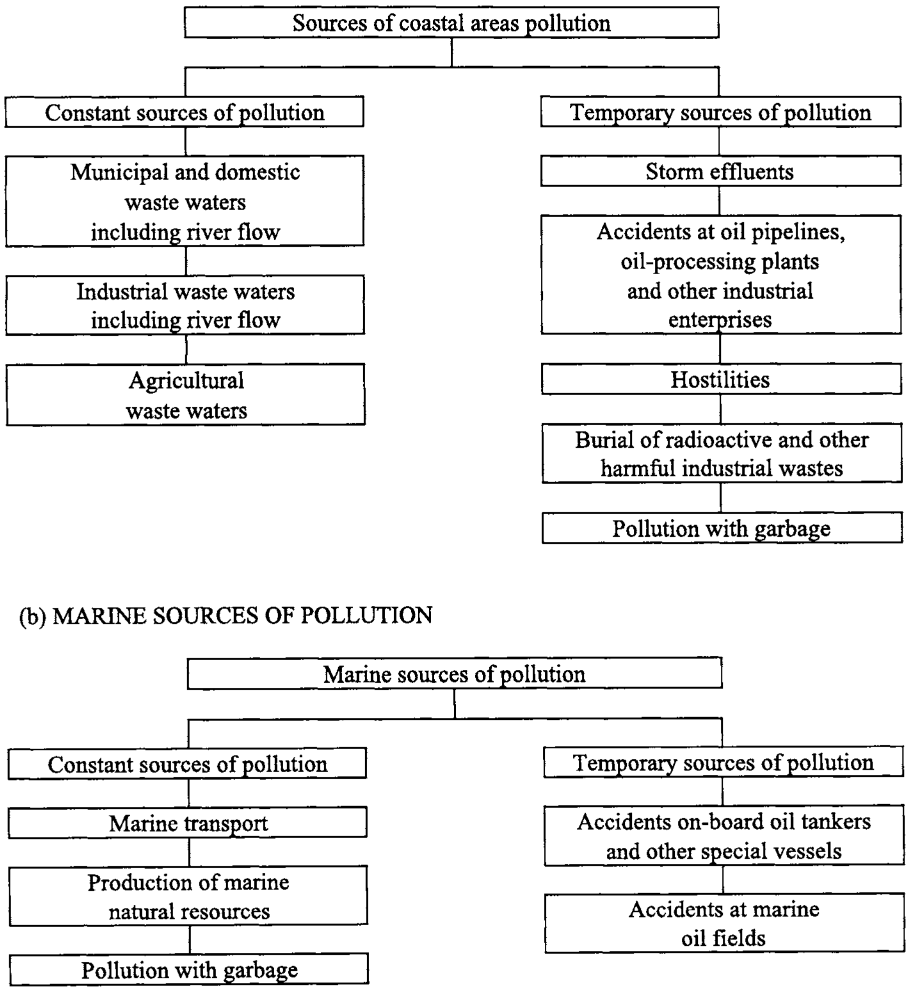

Figure 3.2. Sources of ocean pollution.

Bacterial contamination assumes the appearance of pathogenic microorganisms in the marine environment which were not previously prevalent there. Such pollutants are carried in waste water from slaughterhouses, tanneries, leather and fur manufacturing plants, and microbiological industrial enterprises.

Domestic wastes include effluents from kitchens, bathrooms, lavatories, etc., where organic substances constitute 85% of the total volume of effluents.

In industry, water is used as a heat carrier, heat consumer, solvent and means of transportation. Frequently, water is used for all these purposes simultaneously. Many machine-building, metal-processing and chemical enterprises, and thermoelectric and nuclear power plants use water as a cooling agent (about 80% of all the water involved in production processes). Water used for this purpose becomes heated, but, due to its contact with raw materials, finished products or parts of the plant equipment, it can become contaminated too.

In petrochemical and chemical plants, where water is used as a solvent and included in finished products, specific effluents are formed.

In some industries, water is used as an "environment adsorber" and means of substance transportation (for washing raw materials etc.). Here the water becomes contaminated with mechanical pollutants and dissolved substances.

The quantity of domestic waste water is governed by the volume of water used by the population in the given region, whereas the quantity of industrial waste water is determined by the type of technological processes involved and so varies greatly depending on the type of industry.

Therefore, the amount of industrial effluents discharged into rivers or seas also varies, whereas the discharge of domestic effluents into various bodies of water is more or less constant for the given region. Industrial waste waters differ greatly in their chemical composition. Organic synthetic substances or mineral substances can prevail. Their degree of toxicity also varies.

Due to the expanding and intensifying exploration and development of oil and natural gas resources on the continental shelf, the danger of marine environment contamination has increased greatly. Gas, oil and oil products finding their way into the sea from such marine oil and gas fields are dangerous, because they have a pronounced negative effect on marine ecosystems [89].

Persistent pollutants that penetrate deep into sea water are detained in the water column and can circulate there for dozens and even hundreds of years. They are particularly dangerous for the life of the bathyal and abyssal ocean. Comprehension of our lack of information about the degree of water contamination in open sea areas should stimulate new research, and the improvement of instruments for observation and analysis.

Extremely dangerous contamination of vast water areas results from disastrous oil spills (from tankers and other vessels transporting oil and oil products, and from oil pipelines, etc.). Marine environment contamination from oil and oil products is now acquiring a global character. At present, the amount of oil hydrocarbons entering the sea as a result of oil spills is equal to 0.23% of global oil production. Numerous accidents involving oil tankers, carrying up to 400 thousand tons of oil, and disasters occurring in the process of oil exploration and production on the continental shelf have led to petroleum contamination of one-third of the whole World Ocean's area [90].

Oil and oil products finding their way into the marine environment undergo changes resulting from effects of physical, chemical and biological processes. Immediately after the occurrence of an oil spill, the spreading, evaporation and emulsification of oil begin. As a result of chemical processes, oil dissolution, oxidation and microbial decomposition commence.

In calm sea water, 1 m^3 of crude oil forms a slick of diameter of 48 m, the average thickness of the oil spot being 0.1 mm. During a heavy storm at sea, oil spreading is insignificant, and the oil tends to form clots. Winds and sea currents carry oil slicks and clots over large distances [89]. The rate of oil and oil products evaporation depends on the type of oil, season of the year, and geographical latitude of the spill's location. In subtropical, tropical and equatorial zones, the evaporation rate of light oil fractions is quite high, which leads to a rapid decrease in its toxicity. By contrast, in the cold waters of Arctic and Antarctic seas, the evaporation rate is low, and chemical reactions between oil and water occur slowly. Cold water therefore remains polluted with oil and oil products for a long time.

Oil films formed on the ocean water surface affect capillary waves, the temperature of the surface microlayer, and reflection and transmission of electromagnetic waves. They also suppress gas exchange processes, micro-scale turbulence and convection processes near the water surface, and modify the formation of sea foam and air bubbles which promote the self-purification of water masses.

The solubility of oil and oil products in sea water depends mainly on their chemical fraction composition. The solubility of aromatic hydrocarbons (benzene, toluene, xylene) is much higher than that of normal paraffins.

Oil and oil products have a negative effect on many living organisms throughout the food chain. Oil films not only disturb the processes of heat, moisture and gas exchange between the atmosphere and ocean, but also affect physicochemical and hydrobiological conditions in the ocean, and the climate and oxygen balance in the air.

Oil and oil products spilled on the water surface are harmful to marine ecosystems. During the first hours of contamination, phytoplankton are the worst affected: their photosynthesis is suppressed because the oil film blocks sun rays, thus preventing oxygen formation in the water. As a result, the plankton, which are the main food for numerous marine organisms, cease to breed, and so the bottom fauna suffers too. In the microecosystem of the water surface layer, various organisms are found, including young fish and invertebrates. It is this important microecosystem that takes the first and heaviest blow from oil contamination.

The soluble components of oil and oil products are extremely poisonous. Their presence in the water is harmful to marine plants and animals, especially fish. Oil spills cause the death of whole fish stocks and adversely affect waterfowl.

Oil and oil products have a negative effect on physiological processes in marine animals, causing pathological changes in their tissues and organs, and violating the functioning of their enzymatic and nerve systems. In some cases, oil becomes a kind of drug for marine animals: it has been observed that some fishes, having once "tasted" oil, do not try to leave the contaminated area [91].

Oil emulsification in the marine environment occurs as a result of wave formation on the water surface. As a result of the loss of light fractions and of mineral substance adsorption, the oil density increases, and it settles onto the sea bottom. During spills of heavy oils and mazut, sedimentation processes occur at higher rates. On the bottom of the seas and oceans, such oil products become included in bottom sediments. Fine-grain clay deposits absorb much more oil and oil products than do silty, sandy or stony ones.

Oil biodegradation occurs more quickly in shoals, where more microorganisms are found. The rate of biodegradation is determined by the presence of biogenic substances, dissolved oxygen concentration, and water temperature.

Oil and oil products are oxidized under the effect of sunlight and atmospheric oxygen. Cyclic hydrocarbons are subject to quicker oxidation than are other oil products. Oil floating on the water surface as a film is oxidized more quickly than emulsified or tar-like oil. Much oil is detained in the surface layer as clots of various sizes.

There is one more extremely powerful source of ocean contamination with petroleum hydrocarbons – long-distance atmospheric transfers. In the opinion of some scientists, such long-range transfers of oil and oil products are caused by the evaporation and incomplete burning of benzene, kerosene and other light fractions of oil. The residence time of these substances in the atmosphere is 6–28 months, 90% of such products falling out as precipitation in the Northern Hemisphere.

The concentration of oil hydrocarbons in ocean water varies over a wide range, reaching a maximum of 350 mg/liter in the Mediterranean Sea. The highest concentration values are observed in a thin water surface layer and at the water–air interface.

There is an assumption that in the first decade of the twenty-first century, the input of oil and oil products to the ocean will reach 30 million tons. This will create a dangerous ecological situation, which will be aggravated by global ocean pollution with pesticides and other toxic substances of anthropogenic origin, harmful to both marine ecosystems and human beings.

Components of oil, such as polycyclic aromatic hydrocarbons, some of which are widely spread in the ocean, are carcinogenic. It can be assumed that marine environment contamination with oil and oil products, contributing to the proliferation of polycyclic aromatic hydrocarbons in sea water, is endangering marine ecosystems, causing variations in the functioning of their biotic components. In addition, polycyclic aromatic hydrocarbons can be accumulated in hydrobionts.

The main pollutants finding their way into the marine environment are presented in Table 3.1. According to their physical state, pollutants can be classified as solid, liquid or gas. Gaseous (volatile) organic pollutants are represented by dichlorethane, freon, etc. Heavy metals and their compounds are included among the solid pollutants. They find their way into the ocean with waste waters, or as a result of long-range atmospheric transfers, as mentioned earlier. The increasing concentration of heavy metals in the atmosphere is explained by the growing scale of natural resources processing: oil and coal burning, ore production, metal smelting, etc. [92]. The problem of marine environment contamination with heavy metals and their compounds has become acute due to:

- high concentrations of heavy metal compounds in coastal areas and inland seas;
- accumulation of heavy metals in hydrobionts in doses dangerous even for humans;
- formation of highly toxic metal–organic complexes (ligands) which are included in the abiotic component of ecosystems.

The highest level of ocean pollution with heavy metals and their compounds is observed in coastal waters and inland seas as a result of effluent disposal into rivers flowing into oceans and seas. Heavy metal contamination resulting from long-range atmospheric transfers is no less important. The global character of such transfers is proved by the example of mercury occurring in the ice of Greenland [93].

Mercury is the most toxic of the heavy metals. Having found their way into the aquatic environment, molecules of mercury come into contact with organic and inorganic suspended particles and precipitate onto the sea bottom. The average concentration of mercury in ocean water varies from 5 to 100 ng/liter [94]. Water pollution with mercury leads to a decrease in the primary production of marine ecosystems. In zones with the highest concentration of this metal, the concentration of microscopic green algae, which synthesize organic matter and release oxygen, is decreased. Particles of mercury are adsorbed by phytoplankton and then transferred to aquatic organisms all the way up the food chain. This metal, like other heavy metals, is intensely concentrated in the muscles and tissues of fish and benthic animals, leading to dangerous ecological and genetic consequences. For example, the average coefficient of accumulation by phytoplankton is 4×10^5 for lead, 3.4×10^3 for mercury and 2.1×10^4 for cadmium [95].

Table 3.1. Principal pollutants that find their way into the marine environment

No.	Substance	Natural inflow (1000 tons per year)	Overland flow and direct contamination (1000 tons per year)	Input via the atmosphere (1000 tons per year)	Composition of pollutant input (%)		
					Natural input	Input from the land (coastal zone)	Input via the atmosphere
1.	Oil and oil products	100	5100	600	0.8	87.9	10.3
2.	Oil-originated hydrocarbons	–	–	90000	–	–	100
3.	Heavy metals:						
	Lead	100	3.5	300	24.9	0.8	74.3
	Mercury	3	1.5	80	0.7	3.6	94.7
	Cadmium	0.5	0.5	10	0.05	0.05	90.9
4.	Chlorinated Hydrocarbons:						
	DDT	–	2	25	–	0.4	92.6
	Aldrine	–	2	25	–	0.4	92.6
	Benzene-hexachloride	–	2	50	–	0.9	96.7
	Polychlorinated biphenyls	–	4	20	–	16.7	83.3
5.	Volatile organic Compounds:						
	Dichlorethane	–	–	500	–	–	100
	Freon	–	–	500	–	–	100
	Others	–	–	3000	–	–	100

Reprinted from: A.V. Souvorov. *Economic efficiency of aquatic biological resources reproduction.* Abstract, Candidate Dissertation, Moscow State University, Moscow, 1990.

The concentration of cadmium in open sea water varies within a smaller range than does mercury, but this metal is intensely accumulated by biota (mainly in fish branchiae, liver and kidneys). It is readily released from bottom sediments. For the purpose of cadmium monitoring, it is recommended to determine the concentration of cadmium in fish liver [96].

When determining the concentration of lead in sea water, we are faced with considerable scatter in observation data, which is explained, primarily, by the low content of this metal in the aquatic environment. The highest concentrations of lead are observed in bottom sediments, where it is buried. The content of lead in phytoplankton and fish, on the whole, is quite low, which is why it is expedient to use benthic organisms for the purpose of lead monitoring [97].

Zinc and copper are readily accumulated by phytoplankton, and when the latter die these metals find their way into bottom sediments and some mollusks [97]. High concentrations of zinc in the marine environment are connected with biological processes occurring in the water column and on the sea bottom. By contrast, there is little contamination of sea water with copper. However, it is important to note that copper deficit in natural waters is the factor limiting organic matter production by microorganisms.

The high toxicity of chromium is explained by the high solubility of its compounds in sea water. Increased content of chromium salts has been found in polychaetes.

Arsenic, like mercury, precipitates onto the sea bottom. High concentrations of this element have been traced in hydrobionts. However, it does not become more intensely accumulated as it is transferred along the food chain.

Mechanisms and reasons for bioaccumulation of heavy metals have not yet been properly investigated, but there is convincing evidence of damage to living organisms caused by these metals, including blood plasma pathology, destruction of branchial membrane, histopathology in tissues, decreased resistance to epidemic diseases, etc. Some toxic metals directly affect chromosomes, causing genetic diseases in hydrobionts.

Being accumulated in marine organisms, heavy metals undergo complex transformations: some of them find their way into solution from marine organisms and circulate in the upper water layer, but most metals leave the surface water layer and adsorb on suspended particles [98].

Unlike oil and heavy metals, chlorinated hydrocarbons are regarded as unnatural components of the environment, and so they are most dangerous for living organisms. Chlorinated hydrocarbons (pesticides, DDT, benzyl-hexachloride, etc.) and polychlorinated biphenyls are widely used in industry and agriculture, and, therefore, circulate in the environment. Long-term application of these substances in many coastal countries has resulted in their spreading and accumulation in marine ecosystems around the globe. The chemical industry produces about 1000 substances in this group. Over the last two decades, more than 370,000 tons of polychlorinated biphenyls have been discharged into the environment, of which 230,000 tons are now located in ocean waters [99]. A two-fold increase in the concentration of these substances in terrestrial ecosystems is regarded as the reason for their accumulation.

Chlorinated hydrocarbons, DDT, its derivatives and metabolites, and polychlorinated biphenyls are found in many areas of the ocean in different components of the marine ecosystems. Being nonpolar substances, chlorinated hydrocarbons are lipid soluble and that is why they can accumulate in lipid fractions of hydrobionts, as well as in oil clots in the ocean.

In the ocean waters of the Northern Hemisphere, due to the proximity of much industrial activity to the coast, the concentration of polychlorinated biphenyls always exceeds their concentration in the waters of the Southern Hemisphere. Nevertheless, the sea water of the Southern Hemisphere are subject to constant and very intense contamination with all sorts of pollutants of anthropogenic origin. Thus the rate of polychlorinated biphenyls sedimentation in tropical ocean waters is lower than in the ocean waters of subtropical and temperate zones. This suggests the possibility of dangerous chronic pollution of sea water with polychlorinated biphenyls.

Being highly toxic and very persistent, chlorinated hydrocarbons can be accumulated in hydrobionts and transferred along the food chain. Thus, the average coefficient of accumulation by zooplankton is 6.4×10^3 for polychlorinated biphenyls, and $1.2. \times 10^4$ for DDT. For marine mammals, these values are 1.3×10^7 and 3.7×10^7, respectively. For icthyofauna, the respective values are 1.7×10^5 and 3.1×10^5 [99].

The pattern of chlorinated hydrocarbons proliferation in the marine environment allows us to suggest that a certain dynamic balance is established between the concentration of polychlorinated biphenyls and DDT (including its metabolites) in sea water, and their concentrations in marine organisms. Proof of accumulation of these chlorinated hydrocarbons in lipid fractions of marine organisms has been obtained, as mentioned earlier. The persistence of chlorinated hydrocarbons, their ability to accumulate in marine organisms, their high toxicity and the resulting strong mutagenic effect make the problem of contamination of the marine environment with these substances extremely grave.

Radioactive elements, due to their unique properties, stand apart from other elements polluting the marine environment. The main sources of artificial radionuclides in the ocean are:

- explosions of nuclear bombs and other devices;
- burial and disposal of radioactive-contaminated waste from the nuclear power industry;
- accidents involving nuclear-powered vessels and discharge of radioactive-contaminated waste from them.

Emissions of radioactive substances from nuclear weapon tests cause the proliferation of these substances over vast areas of water. It is believed that the release of radioactive substances above the ocean is more intense than above the land. Observed data testify to the fact that global precipitation of nuclear explosion products remains one of the most dangerous sources of marine environment contamination with radionuclides. It has been found, in particular, that the ratio of the total amount of cesium-137 contained in the waters of the north-western Pacific to its input into the corresponding ocean water surface is in the range 1.0–2.1 (1.6 on average). This ratio for strontium-90 is in the range 1.5–2.5 (the average value being 1.9). Higher concentrations of radionuclides are observed in the surface layers of the ocean. At the same time, the presence of a certain quantity of radionuclides distributed over the whole water column means that their transport by suspended particles is an important factor controlling the vertical distribution of radionuclides [100]. Radionuclides are intensely accumulated by biota, adversely affecting marine ecosystems.

Recently, numerous proofs of mutagenic effects caused by marine environment contamination with various chemical substances, such as chlorinated hydrocarbons with a short molecular chain (e.g. vinyl-chloride, pesticides, polychromatic and polycyclic hydrocarbons, primarily benz(a)pyren) have been obtained.

Bacterial activity in the marine environment cannot by itself ensure detoxification and destruction of the whole mass of pollutants (especially persistent ones) finding their way into the ocean. The toxic character of biomass and hydrocarbon oxidizing microflora (including bacteria that oxidize polycyclic aromatic hydrocarbons) and intermediary products of oil transformation cannot be neglected. Excessive development of hydrocarbon-oxidizing microflora can be regarded as secondary pollution of the marine environment.

Microbiological pollution of the marine environment is dangerous for human beings. Discharge of untreated or improperly treated domestic effluents in the coastal zone entails the appearance of pathogenic and conditionally pathogenic microorganisms, which easily adapt to new conditions (especially in desalinated or eutrophicated waters), and develop in hydrobiont-filters, which are of great environmental significance and are also objects of trade (oysters, mussels, etc.).

Note that in sea water contaminated with organic substances, various pathogenic and conditionally pathogenic microorganisms cannot only preserve their vital activity but also breed. The atmospheric transfer of such microorganisms to the land and open water areas is proven. Proliferation of pathogenic intestinal microorganisms (including cholera vibrios) in coastal waters and the mollusks inhabiting them is very dangerous. Mariculture projects should therefore not be approved without preliminary implementation of measures aimed to protect the coastal zone against microbiological pollution.

A very important consequence of marine environment contamination, which should not be neglected, is the intense eutrophication of inland seas and ocean coastal areas. The phenomenon of *human-induced eutrophication of the marine environment* can be defined as a consequence of the increasing intensity of primary biological production processes resulting from human economic activity and caused by the abundant input of readily degradable substances and nutrients (mainly with domestic and industrial waste waters). Biogenic elements, such as phosphorus and nitrogen, are the most widespread pollutants entering the ocean through river flow. Marine environment eutrophication is observed even in some pelagic areas of the ocean, which is explained by long-distance atmospheric transfers of suspended organic particles and nutrients.

It is important to note that substance particles that settle on the ocean surface affect the larvae and fry of many valuable types of fish and play an important role in processes of pollutant transformation and destruction in the marine environment. In addition, many organisms accumulate and later release chemical toxicants and radionuclides, whereas the vital activity of certain bacteria promotes the formation of metal–organic ligands, which are very toxic.

Mechanisms of transformation of gaseous and aerosol pollutants that find their way into the marine environment have not been sufficiently studied. This is because such mechanisms are different for different substances. There is no doubt, however, that such transformations entail marine environment contamination on a global scale.

The "water–bottom sediment" contact zone is a critical one. Here, the coefficients of pollutant accumulation are much higher than in the water column. Most pollutants (such as heavy metals and their compounds, persistent chemicals, etc.) adsorb on suspended particles, pass through the whole water column, and then accumulate in the bottom sediments, where they undergo complex transformations, mainly due to the activities of anaerobic bacteria. The intermediary products of pollutant transformation by benthic organisms, and processes of secondary contamination of the marine environment, caused by wave and wind phenomena in coastal areas and shoals, have recently become the subject of scientific studies.

The vertical distribution of pollutants in the water column and their removal from the latter are determined mainly by the character and rate of sedimentation processes. Active processes of chemical and microbiological oxidation of allochthonous organic matter occur on the surface of suspended particles (including those of biogenic origin). Their sedimentation rate is determined by the quantity of particles and their dimension, and by the hydrodynamic characteristics of the water area being studied.

The increasing anthropogenic load on the aquatic environment is causing degradation of marine ecosystems in certain sea basins, stable changes in the structure and functioning of biocenoses, and negative sanitary-hygienic consequences. The natural cycles of vital elements such as carbon, nitrogen, phosphorus and sulfur are disturbed. Processes of heat, moisture, and gas circulation between the atmosphere and ocean are affected too. The most important affect, however, is that human-induced contamination of the marine environment leads to decreased biological productivity in marine ecosystems, and disturbances in their capacity for self-renewal, which could lead to their complete destruction.

3.2. ECOLOGICAL CONSEQUENCES OF MARINE ENVIRONMENT CONTAMINATION AND THEIR ECONOMIC EVALUATION

Ecological consequences of any impact on marine ecosystems are changes undergone by these systems due to anthropogenic factors, including those caused by the exploitation of marine natural resources, i.e. they are changes that do, or might in the future, affect the results of human economic activity in the coastal region.

The ecological and economic consequences of marine environment contamination are only beginning to be understood. Under the impact of toxicants, various changes occur in the ocean ecosystem: from a gradual decrease in the size of individuals and restructuring of their enzymatic systems to the cessation of breeding and the death of organisms. Due to intensifying pollution of the ocean, the stability of marine ecosystems is disturbed; eutrophication develops at high rates; the biological productivity of ecosystems decreases; and mutagenic and carcinogenic effects begin to manifest themselves, particularly in coastal microorganisms. All these consequences can and must be estimated from an economic viewpoint, irrespective of when they occur and the form in which they become manifest.

Investigation and systematization of ecological consequences of the impact of pollutants on marine animals and plants are of great significance for ecologonomics, because they create the necessary prerequisites for ecologonomic forecasting of marine ecosystem conditions and for determining the permissible anthropogenic load on them. The *standardization of anthropogenic load* on an ecosystem involves determining the critical load and critical (limiting) state of marine biocenoses and their individual components. In this respect, it is relevant to study the so-called *assimilation capacity of the marine ecosystem* as an integral characteristic of the ability of its biocenosis to accumulate, transform and remove pollutants from the ecosystem under conditions that preserve its main features and parameters. Water mass transfer, microbial oxidation of organic compounds and biosedimentation of suspended matter considerably affect the assimilation capacity of the marine ecosystem. Quantitative evaluation of assimilation capacity for a certain pollutant allows us to determine the ecological reserve of the marine environment and the value of the maximum permissible load on individual areas of the ocean.

Different components of marine ecosystems are characterized by different resistance to individual pollutants and different response periods to damaging impacts. Thus the degree of damage caused to marine ecosystems can be assessed only from studying all its elements (bacterio-, phyto- and zooplankton, zoobenthos, ichthyofauna). A wide range of variations in marine biota results from the impact of toxicants. As described in section 3.1, marine environment contamination results in the accumulation of toxic substances in marine organisms, microbiological pollution of coastal areas, progressive eutrophication (and, as a result, the occurrence of "red tides"), decrease in biological productivity of marine ecosystems, and disappearance of certain individuals and species from the community of marine organisms. Marine environment contamination also leads to manifestations of mutagenic and carcinogenic effects. All this entails disturbance in the balance of marine ecosystems, which, in the long run, affects the development of different branches of the marine economy.

For the last two decades, basin pollution fields have spread widely, reaching a global level. This affects the chemical regime of the ocean, whose formation took millions of years. Ecological and biological consequences of variations in the chemical composition of sea water constitute a whole chain of interrelated reactions; the transformation of natural biocenoses and the decrease in their biological productivity are the most significant manifestations of such reactions. Figure 3.3 presents a general scheme of the ecological consequences of marine environment contamination.

It is a well-known fact that toxic substances affect individual processes in marine organisms, which result in changes in: the dimension of cells and their chemical composition, the character of enzymatic processes, breathing, osmosis, growth and breeding, and damage to the ability of hydrobionts to take their bearings in space, etc.

Biological consequences of marine environment contamination include changes in the biochemical, morphological, ecological, physiological and even genetic properties of whole ecosystems and their components.

Analysis of the background conditions of the aquatic environment should be paid special attention in environmental studies. Intense local anthropogenic impact can result in complication of the ecological structure of biocenoses (ecological progress) or its simplification (ecological regress).

Ecological progress and ecological regress are characterized by specific features related to radical changes in many biological processes and the trend of these processes [101]. In the case of weak or local human impacts affecting the background conditions of the ecosystems, the changes occurring in biocenoses can be described as *ecological modulations*, understood as variations in the ecological structure which do not lead to its complication or simplification. They are not connected with profound restructuring of ecosystems; they reflect only minor changes in water quality parameters [102].

Thus, even under conditions of low concentrations of pollutants in sea water, marine biocenoses can undergo certain changes, whose consequences can be critical for both the ecosystems of individual sea basins and the ecosystem of the ocean as a whole. Such changes include: decrease in species diversity; damage to the ratio and rates of production–destruction processes; anomalies in dissolved oxygen dynamics; succession of dominant species in biocenoses; and disturbance of biocommunications in communities of marine organisms. The probability of the so-called *synergetic effect* (combined impact of several impacts) occurring is high when chemical pollutants play the role of catalysts.

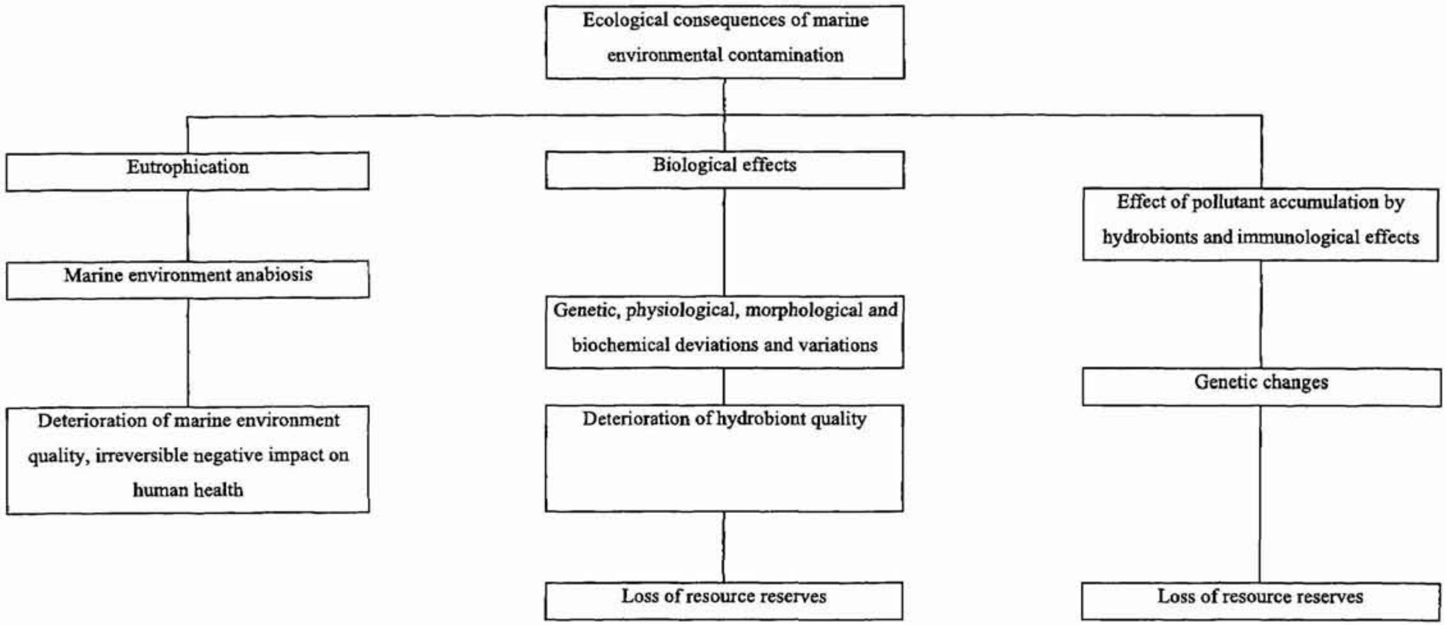

Figure 3.3. Ecological consequences of human impact on marine ecosystems.

Very often, ocean contamination entails large-scale destruction of marine fauna (e.g. the death of waterfowl during oil spills).

Human-induced changes in the physical properties of the ocean (water salinity and transparency, currents, evaporation rate, etc.) can have serious consequences for marine ecosystems. Increasing water turbidity, which has already occurred in the shelf area as a result of large-scale production of marine mineral resources, may in the near future destroy phytoplankton and thus decrease the rate of oxygen photosynthesis, and hence the bioproductivity of the ecosystem [103]. The consequences of damage to the benthos system, caused by roiling huge masses of water during the mining of iron–magnesium concretions in deep-water areas of the ocean can also be grave.

In Arctic and Antarctic regions, marine environment contamination has certain specific features. Here, even small-scale pollution is extremely dangerous; due to the low water temperature, pollutants can be preserved for dozens of years and their degradation rate is very low.

The intensified contamination of the open ocean, coastal zones, inland seas, bottom sediments with toxic organic substances, oil products, heavy metals, pathogenic microorganisms, eutrophication and atmospheric transport and precipitation of pollutants, described in detail in section 3.1, have serious adverse effects on marine ecosystems. The ecological consequences of such contamination are shown in Figure 3.4.

Uncontrolled discharge of pollutants into bodies of water causes marine environment contamination and violates the normal functioning of marine ecosystems. Due to the global atmospheric circulation and the integral character of the ocean itself, local anomalies in one part of the ocean affect natural conditions in neighboring regions, and thus gradually acquire a global character.

Fishing is the branch of marine industry which is most affected by pollution, the more so since areas with the highest values of pollutant concentrations coincide in space with areas of greatest biomass and the most productive zones of the water surface. The negative effect of contamination on fishing is most pronounced in coastal areas of the temperate zones.

According to certain estimates, the annual decrease in nekton production (including fish catch) caused by marine environment contamination is about 20 million tons, calculated from optimum estimates of fish catch in a hypothetical clean ocean [104]. Bearing in mind that fish stock is most vulnerable in the areas of most intense fishing, we must presume that the greater part of these 20 million tons should be attributed to fish "undercatch". According to preliminary calculations, additional product worth US$3 million might have been generated from this undercatch.

On the whole, the problem of estimating the damage caused by marine environment contamination can be arbitrarily divided into strategy and tactics. In cases where not all the negative effects can be expressed for certain in monetary terms, ecological damage can be determined for the fishing industry by means of calculating the undercatch described in the previous paragraph, and the cost of the product that might have been obtained from processing this undercatch.

However, taking into consideration the complicated structure of marine ecosystems, underestimated parameters are often used to evaluate such damage when solving tactical problems in the planning and management of the coastal economy, so that financial compensation to the fishermen by the branch of economy causing such damage did not exceed the profit that that industry would make from production and processing the marine resources it uses. This is what the principle of economic competition between various functions of marine economy in the given sea basin or region is based on.

In solving strategic problems for the distant future, underestimated economic damage parameters cannot be used, because, in the example considered, the damage will consist not only of damage caused to the fishing industry. Here it is important to use improved methods of calculating the value of such damage on the basis of a complete account of numerous economic parameters. Today, the economic consequences of marine environment contamination are, in practice, neglected (with the exception of such elements of damage that cannot be estimated without involving a certain criterion expressed as unit compensational expenditure on eliminating consequences of marine environment contamination).

From the methodological standpoint, quantitative evaluation of damage caused by marine environment contamination is the most difficult task. Note that calculation of damage caused by pollution lasting for a certain time period, although labor intensive, is not very difficult to implement, whereas quantitative evaluation of the total damage caused by human economic activity to the ocean as a whole is an extremely difficult task, in spite of the constant improvement in methods of marine research. At present, we cannot properly estimate the consequences of marine environment contamination for the ocean ecosystem (both as a whole and within individual sea basins).

In general, damage caused by marine environment contamination consists of two components:

(1) cost of eliminating direct consequences of pollution;

(2) cost of damage caused to natural resources in the marine environment.

The second is connected with material and moral losses, which can hardly be expressed in monetary terms (e.g. losses from a reduced demand for fish that has become contaminated, or from reduced tourist and recreational activities in polluted water areas and beaches, etc.). It is very difficult to estimate such consequences of marine environment contamination, which manifest themselves only after many years or even a century.

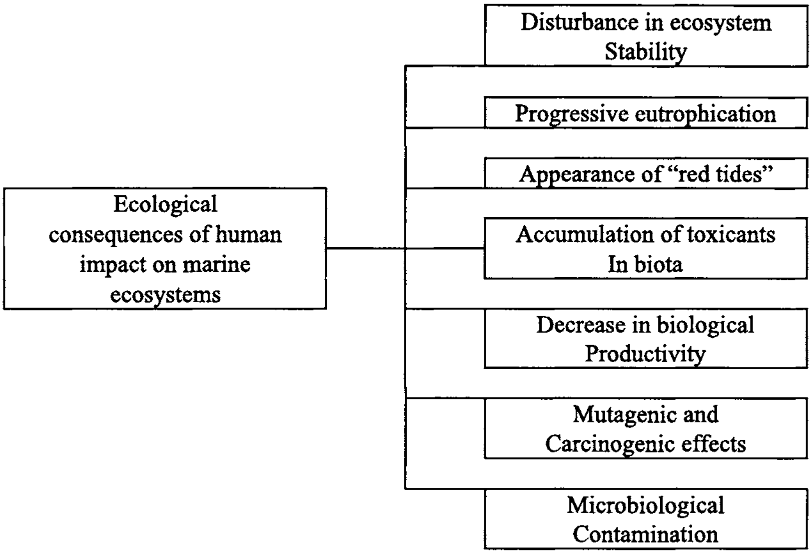

Figure 3.4. Ecological consequences of human impact on marine ecosystems.

Therefore, the solution of tactical (supposedly short-term) problems should not be restricted to estimating the damage caused to the fishing industry and the expression of such damage in monetary terms. The total damage should be determined taking into account all the factors contributing to it.

The following costs relate to marine environment contamination:

- compensation for damage caused to the marine ecosystem (E_c);
- compensation for the loss of valuable products from the ecosystem (E_l);
- costs of reducing pollution to the permissible level, if such pollution continues (E_p).

For tactical problems, the sum of the first two types of damage corresponds to the required value of economic damage, i.e.:

$$D'_n = E_c + E_l \tag{3.1}$$

where

D'_n is the damage of tactical character.

In solving strategic problems, economic damage should be calculated as the sum of all the above three components:

$$D''_n = E_c + E_l + E_p \tag{3.2}$$

where

D''_n is the damage of strategic character.

Production of natural resources from marine ecosystems will be efficient only when the total of the expense of marine environment conservation and the value of the overall damage caused to it by human economic activity is minimum under the conditions of achieving maximum economic effect.

In our attempts to solve ecological problems with the help of economic methods, we must be guided by the principle of marine environment optimization, according to which, on the one hand, inevitable changes in the marine environment are not permissible and, on the other hand, the balanced state of marine ecosystems is preserved.

The ecologonomic approach allows us to determine the damage resulting from pollution, not only for marine ecosystems of individual sea basins, but also for the ocean as a whole. The values of damage involved in tactical and strategic problems are determined as follows:

$$D'_t = \sum_{n=1}^{n} D'_n \tag{3.3}$$

$$D''_t = \sum_{n=1}^{n} D''_n \tag{3.4}$$

where

n is the number of marine ecosystems.

It should be noted that the damage analyzed can have a natural cause (as opposed to damage). Such natural damage can be classified according to the form in which it manifests itself (visible and tangible, or invisible and intangible), and according to the time when it manifests (it may or may not coincide in time with marine environment pollution).

There are various approaches to the economic evaluation of ecological consequences of ocean pollution. All of them suggest the economic evaluation of resources that are excluded from production, which is, in principle, the same as quantitative estimation of the deterioration of resource quality due to pollution.

The effect of pollution on certain types of marine natural resources depends not only on the volume, concentration and toxicity of pollutants, but also on the so-called "ecological stability" of these resources, the self-purification capacity of the marine environment and some other factors of a regular or stochastic character.

For biological resources, the model for determining ecological damage, depending on the pollutant concentration for a number of populations m at a certain moment in time t for a certain water area R, can be presented as:

$$A_m(t) = \int_R \sum_{jn} C_{jn}(R \cdot t) \cdot E_{jmn} \cdot N_m(R, t) \, \mathrm{d}R \qquad (3.5)$$

where

m is the number of populations in the marine ecosystem;

A_m is the value of environmental damage for m populations;

C_{jn} is the concentration of the j-th pollutant in environment n;

E_{jmn} is the toxicity of the j-th pollutant for m populations in the environment n;

N_m is the number of organisms in the given population.

However, calculations with this model are very complicated, which confirms the necessity of using calculations (however approximate) for unit elements of the natural damage caused by marine environment contamination.

The economic evaluation of damage resulting from marine environment contamination within a particular water area always has its own time range. The estimation of such damage is therefore always implemented for the beginning and the end of the given time interval. In this case, the total value of change in the natural resources potential will reflect the total economic estimate of the damage caused by marine environment contamination in the given water area and for the given time interval.

The rent-based approach to the economic evaluation of damage resulting from marine environment contamination is more difficult to implement, but, at the same time, it has better substantiated methodology. It is based on the principle of optimum functioning of the economy. According to this approach, only such resources should be evaluated whose involvement in the production process is environmentally safe and economically expedient at present and in the near future. In this case, ecological damage resulting from a decrease in resource potential is determined based on the decrease in economic effect and should be compensated for by the branch of industry responsible, at its own expense. In principle, as for damage compensation, this concept is similar to the neoclassical theory of natural resources management, unlike the neo-Keynesian theory, envisaging that the compensation should equate not to the value of the damage but to the cost of restoring normal functioning of the natural environment.

A system of economic estimates of damage, its consequences and compensation for it is multipurpose. First, this is the basis for the creation of efficient mechanisms of natural resources management; it allows one, by means of withdrawing additional income (arising from the use of improved natural conditions) to:

- create equal economic conditions for individual enterprises and companies;
- stimulate efficient operation of the latter;
- ensure rational marine resources production;
- protect natural resources by means of elaborating a better system of penalties and compensation for the damage caused to the marine environment.

These penalties and compensations should stimulate the implementation of nature conservation measures by resource users in order to prevent damage to the natural environment. However, this is possible only for correct specification of sources of financing environmental conservation measures and damage compensation. In our opinion, the cost of products whose production is inevitably connected with harmful effects on the marine environment should include expenses for the prevention of such negative effects. These expenses must be obligatory, and must be compensated for by the resource users. If all such expenses are passed on only to producers and not included in the price of products, this will lead to the cutting back of environmentally harmful industries. At the same time, if the producers do not carry out the necessary nature conservation measures, they should be obliged to compensate for the damage they have caused, at the expense of their own profit. Implementation of nature conservation measures is hampered by the fact that the expenses of preventing the negative impact of economic activities vary greatly, depending on the concentration of industrial enterprises in the given sea basin and on the assimilation capacity of this sea basin. In addition, difficulties arise in quantifying the proportion of damage caused by an individual enterprise from the total damage caused by the combined negative effect of all the enterprises in a particular sea basin or region.

3.3. Methods of Economic Estimation of Damage Caused by Marine Environment Contamination

As was mentioned earlier, the ecological consequences of marine environment contamination are complicated and diverse, and estimation of damage it causes is a very important task.

Nature conservation is a specific type of human economic activity that does not yield any direct profit, despite the appreciable expenses incurred. However, analysis of the economic efficiency of managing the resources of a marine ecosystem allows us to conclude that this efficiency is affected by the efficiency of nature conservation in the region, because nature conservation promotes increased productivity in that ecosystem [105].

In the absence of expenses for maintaining the normal conditions of the marine ecosystem, economic activity is carried out at the expense of nature itself, i.e. at the expense of uncompensated damage to nature.

Contamination of the marine environment, considered as the habitat of marine ecosystems, leads to two types of costs:

(1) costs of preventing the impact of the contaminated environment upon the marine ecosystem;

(2) costs of eliminating the after-effects of pollution.

If complete prevention of pollution turns out to be impossible, then both types of costs will necessarily be incurred. In this case, the cost of eliminating the effects of residual pollution will be proportional to the scale of such residual pollution.

When calculating the damage in question, the structure of costs and their amounts are determined by the scale of human impact affecting the given marine ecosystem.

Damage caused by marine environment contamination can be measured in natural units that characterize the deterioration of marine ecosystems with the given level of pollution.

The details of evaluating the damage in natural units depend not only on the intensity of actual pollution (pollutant concentrations), but also on the peculiarities of the marine environment itself. Figure 3.5 presents a general scheme for evaluating damage caused by marine environment contamination.

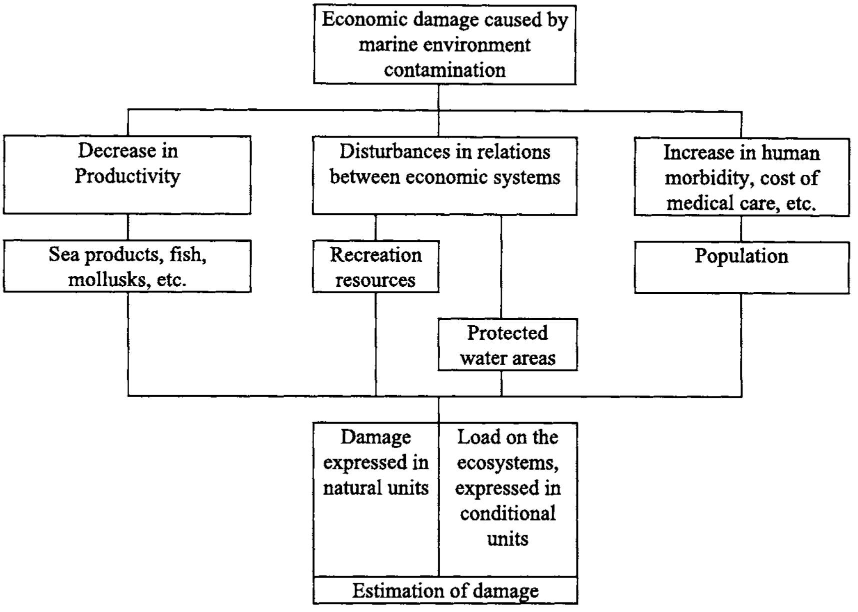

Figure 3.5. Scheme for estimating economic damage caused by marine environment contamination.

In order to estimate in natural units the damage caused to the marine environment by pollution, we can use a technique of eliminating factors that do not pertain to the existing pollution. This technique envisages the comparison of pollution parameters in the test (conditionally clean) basin with the pollution parameters in the contaminated basin. The choice of the test basin should ensure the similarity of all the factors affecting the state of the marine ecosystems in the contaminated and clean basins. With such an approach, the impact of other factors on the state of the given ecosystem is excluded.

As a result of such a comparison, we can determine the modified state of the marine ecosystem using the following formula:

$$\Delta a = |a_t - a_p| \tag{3.6}$$

where

a_t and a_p are state of the marine ecosystems in the test and contaminated basins, respectively.

Another method – the empirical one – is based on statistical processing of observed data on the effect of the most relevant factors (including pollutant concentrations in sea water) in the investigated marine ecosystems. This method allows one to obtain approximate empirical relationships between the ecosystem's state and the pollution level, other factors being equal [106].

A shortage of input date causes difficulties in plotting statistically reliable relationships. Frequently, no reliable input data are available at all. Incomplete assessment of factors affecting conditions of pollutant spreading over the water area in question, and the composition of the populations of the marine ecosystem, in addition to insufficient accuracy in prognostic estimates should be regarded as the main drawbacks of this method.

As modification of the elimination method, a combined method may be applied in order to obtain greater detail in the results. This allows us to identify and classify the most important contamination factors according to their contribution to the damage, and to predict changes in the load on the marine environment in the future, depending on their effect on the marine ecosystem.

The following coefficients are used for the evaluation of sea basin contamination:

γ_k – a dimensionless constant, determining the comparative negative effect of pollution in various sea water areas;

B_i – an index of the comparative environmental toxicity of the i-th type of pollutant.

The value of coefficient B_i is determined separately for each pollutant according to the formula:

$$B_i = 1(\text{g/m}^3)/EPC \tag{3.7}$$

where

EPC is the ecologically permissible concentration of the i-th pollutant in the given sea basin.

Knowing this value, we can determine the mass of pollutants discharged by every definite source of pollution in any part of the sea water area:

$$M = \sum_{i=1}^{N} B_i \cdot m_i \tag{3.8}$$

where

m_i is the mass of total annual discharge of the i-th pollutant;

N is the total amount of pollutants discharged by the given source.

If various pollutants, differing in their concentration, are discharged to the sea from a single source, the annual mass of discharge of the i-th type of pollutant (m_{ij}) is calculated as proportional to its concentration:

$$m_{ij} = K_{ij} \cdot V_j \tag{3.9}$$

where

K_{ij} is the concentration of the i-th pollutant finding its way into the sea (g/m^3);

j is the type of waste water;

V_j is the annual volume of discharged waste water of the j-th type from the given source of pollution (million m^3).

Thus, having analyzed the definite pollution sources for the given sea basin with the help of the above method, we can easily identify the economic enterprises guilty of contamination, and then apply the appropriate economic penalties to them.

Depending on the ecological situation in the sea basin under review, the values of coefficients B_i and γ_k can either increase or decrease.

Economic evaluation of damage caused by marine environment contamination is defined as evaluation of changes in marine ecosystems, expressed in monetary terms, including the cost of restoring and maintaining the normal marine environment conditions and the cost of eliminating the after-effects of pollution.

Depending on the technique used to measure such damage, two methods of estimating the damage may be suggested. The first one is based on expressing the damage, previously evaluated in natural units, in financial terms. The second method envisages expressing the indices of anthropogenic load bon marine ecosystems, also in financial terms.

In general, using the first method, we can determine the economic damage (D_u) with the following formula:

$$D_u = \sum_{n=1}^{N} \min\{C_k, D_k, S_k(a_k D_k + b_k S_k)\} \tag{3.10}$$

where

N is the ordinal number of the given marine ecosystem;

n is the quantity of ecosystems;

C_k is an estimate in monetary terms of the compensation for unit natural damage caused to the n-th marine ecosystem;

D_k is the damage (expressed in natural units) caused to the n-th marine ecosystem by aquatic environment contamination;

S_k is the cost of preventing the effects of pollution on the n-th marine ecosystem;

a_k and b_k are coefficients characterizing the given marine ecosystem.

As can be seen from equation (3.10), two components are singled out in the structure of expenses. The first component represents the cost of preventing the harmful effect of pollution on marine ecosystems; the second one represents the cost of compensation for negative consequences of such contamination.

The first component of the economic damage is estimated as proportional to the value of additional expenses for preventing negative effects of pollution (e.g. the cost of waste disposal and utilization, waste water treatment, etc.). The estimation of the second component includes determination of the costs of artificial renewal of marine resources, of neutralization of toxicants that have found their way into the marine environment, etc.

Economic damage caused by marine environment contamination can be classified as prevented or actual. If the expenses incurred prevent the pollution completely, we are dealing with fully prevented damage, whose value is equal to the cost of preventive measures. In this case, naturally, no expenses are incurred in compensation for the after-effects of pollution, because there are no such after-effects. If no measures are taken to prevent pollution, we speak of full actual damage.

Based on the data of actual and prevented damage, we can attempt an economic (i.e. expressed in monetary terms) estimation of these two types of damage caused by marine environment contamination.

Prevented damage is estimated as the cost of additional expenses incurred to achieve full or partial prevention of marine environment contamination. Partial prevention of contamination should ensure safe conditions for marine ecosystems, i.e. promote the preservation of their balanced state.

Let us now consider an example of calculating the prevented and actual damage caused by liquid waste discharge employing traditional and wasteless technologies (Table 3.2). As can be seen from this table, there are three variants (or technological schemes):

I – discharge of the whole volume of effluents to the sea;

II – discharge of 50% of the effluents (or 50% recycling system);

III – 100% recycling system (zero effluent disposal).

It goes without saying that under the first variant, the prevented damage will be zero (and the value of useful nature conservation effect will be zero, too), whereas under the third variant both these values are maximum (100%).

Table 3.2. Values of prevented and actual damage in a process of liquid wastes discharge for three different technological variants

Parameters	Measurement units	Variants		
		I	II	III
Actual discharge	1000 m^3	1900	956	–
Prevented discharge	1000 m^3	0	950	1900
Total concentration of pollutants discharged, including:	mg/liter	970	485	–
CN	mg/liter	0.06	0.03	–
Lead	mg/liter	1.4	0.7	–
Mercury	mg/liter	0.11	0.7	–
Oil and oil products	mg/liter	0.68	0.34	–
CNS	mg/liter	0.42	0.21	–
Actual damage	1000 ECU	80.6	43.2	0
Prevented damage	1000 ECU	0	43.2	80.6
Costs of preventing damage	1000 ECU	0	20	76.2
Useful nature conservation effect	1000 ECU	0	26.1	27.4

Reprinted from: A.V. Souvorov & E.V. Fidirko, *Prediction of Ecological-Economic Interaction in the Region.* Uzbek State University, Samarkand, 1987, p. 58.

Another method of estimating damage caused by marine environment contamination is to calculate it from predicted and actual pollution values and enlarged economic calculations.

The following formula is used to calculate the damage:

$$D_u = J_o \cdot m' / T_s \qquad (3.11)$$

where

D_u is the value of damage caused by actual pollution (1000 EUR/year);

J_o is the specific index of a cost evaluation of products, under-received from individual components of marine ecosystems (EUR/m^3) (this value is different for different sea basins, as calculated for 1 m^3 of biologically active water layer);

T_s is the total unit toxicity of effluents under review (g/m^3);

m' is the unit (reduced) mass of pollutants annually discharged into the ocean, minus the mass of discharged effluents with pollutant concentration not exceeding maximum permissible concentration (MPC) (tons/year).

In turn,

$$m' = m - m_{\text{MPC}} \tag{3.12}$$

where

m is the total mass of annual pollutant discharge (tons/year);

m_{MPC} is the mass of annually discharged effluents with pollutant concentration not exceeding MPC (tons/year).

The value of ratio m'/T_s has the dimensions of m^3/year and denotes the volume of water in the sea contaminated during the year with abundant effluents with pollutant concentration exceeding MPC. This value can be determined with the help of one of the two techniques described here.

The first technique is used when the concentrations of pollutants in the greater part of the effluents, and the MPC for these pollutants, are known. In this case,

$$m'/T_s = \sum_{i=1}^{n} m_i / T_{si} \tag{3.13}$$

where

m_i is the mass of annually discharged effluents contaminated with the i-th pollutant, minus the amount of effluents contaminated with the i-th pollutant where the concentration of this i-th pollutant does not exceed MPC (m^3);

T_{si} is the MPC value for the i-th pollutant (g/m^3).

The second technique is used when the concentration of a certain pollutant, and/or its MPC, is not known. In this case, the volume of water contaminated with abundant effluents to a concentration exceeding the MPC is determined by means of biotesting involving hydrobionts, the tests being carried out according to traditional methods. The essence of this technique is the consecutive dilution of effluents and determination of the so-called *threshold* *dilution* (P_r), i.e. the value to which the concentration of toxicants in the effluents discharged must be reduced so that the water would be safe for organisms inhabiting it. Multiplying this value by the volume of effluents, we can determine the volume of water in the basin in which the pollutant concentration exceeds MPC. Then:

$$D_u = J_o \cdot P_r(V_t - V_{MPC}) \tag{3.14}$$

where

V_t is the total volume of effluents discharged (m^3);

V_{MPC} is the volume of effluents where the concentration of pollutants remains within the limits of the MPC.

Both these techniques give underestimated values of damage. Thus, using the first technique, at present, it is impossible to specify all the toxicants (or the most important of them) contained in the effluents; moreover, for many of them MPC values are not established. We know from practical experience that different MPC values are established for the same pollutant in different countries of the world. With the second technique, the toxicity is estimated on the basis of a limited number of parameters (due to the demand to implement such a procedure as quickly as possible). However, these drawbacks have not prevented practical testing of these techniques of estimating the damage caused by marine environment contamination (case studies in the Sea of Japan, Black Sea and Azov Sea). If, in the process of solving practical problems, it turns out to be necessary to make an ecologonomic evaluation of industrial development in a given coastal region, an integrated parameter of specific (unit) contamination of the marine environment should be introduced which allows quantitative estimation of the technogenic capacity of marine ecosystems:

$$I_p = K \cdot S / C \tag{3.15}$$

where

I_p is the specific contamination of the marine ecosystem;

K is a coefficient characterizing the difference between the marine ecosystem under consideration from a certain "standard" marine ecosystem;

S is the concentration of the given pollutant in the marine environment (g/m^3);

C is the cost price of the products of the given industrial enterprise during a period of contamination (1000 EUR).

This value takes into account the geographical position of the given ecosystem and characterizes its saturation in the pollutant, which will give us an idea of the scale of nature conservation activity in the region under consideration.

Another integrated index – ecological capacity of a given enterprise or branch of industry (V) – reflects the effect of this enterprise or branch of industry on the marine environment, the character of the production process (closed cycle or otherwise), the character of waste treatment, and the amount and composition of pollutants affecting the given marine ecosystem. This index can be evaluated for individual enterprises and branches of industry, as well as for the whole ecologonomic system of the given region (the water area and adjoining land area). The value of the ecological capacity reflecting the effect of human economic activity on the marine environment can be expressed (for each individual type of waste) by the following formula:

$$V = M / S \qquad (3.16)$$

where

M is the mass of pollutants finding their way into the marine environment (tons).

Certain quantitative estimates of anthropogenic impact thus obtained allow us to classify industries that use marine natural resources, on the basis of newly revealed limiting factors, which may serve as the basis for elaborating principles of unification of human impact criteria for a particular region. One of the criteria for such unification is the ecologically permissible concentration of the given pollutant. For an integrated index of ecological capacity of the enterprise, the level of its "wastelessness" can be considered as the best unification criterion.

Based on this, we can carry out comparative analysis of technological production schemes and evaluate them from the viewpoint of ecologonomics. The efficiency of natural resources management in the given region also depends on this index.

In order to make alternative decisions concerning natural resources management in the given water area and the adjacent land area, it is necessary to estimate, correctly, the damage caused to the marine environment by present and future human impacts on the ecosystem located there.

The economic category of marine environment quality is important for determining environmental expenses. The quality of the marine environment (just like that of any other aquatic environment) corresponds to the level of disturbances when the total environmental costs are minimized. In turn, minimization of these expenses can be achieved only when a method of natural resources management is selected that will ensure maximum excess of prevented economic damage over the cost of nature conservation measures aimed at preventing such damage. Note also that the maximum economic effect is achieved when closed-cycle or wasteless and low-waste technologies are introduced in the enterprise or branch of industry under consideration.

3.4. Evaluation of the Efficiency of Marine Environment Conservation Measures

Conservation of the marine environment is of primary importance for humankind; therefore, it should become a central element in the marine policy of many countries [106].

In the document adopted by the United Nations Conference on Environment and Development (Rio de Janeiro, 1992) [14], there is a call to coastal countries to take all necessary steps to control ocean contamination. At present, there are numerous agreements on marine environment protection against pollution, and principles of environment conservation are now becoming generally accepted principles of international law [107]. These international agreements have led to considerable changes in approach to marine environment contamination control, manifest in measures on marine navigation regulation, response to oil spills, and all manner of regulating measures in coastal water areas [108]. So-called "marine protected areas" have been established by international organizations to protect particularly vulnerable regions in the context of regional marine conventions of the United Nations Environment Program (UNEP), and new concepts (e.g. the concept of "particularly sensitive areas") have been developed within the framework of the International Maritime Organization (IMO).

In the European Union, the Fourth Program on Environment Conservation has already been adopted, and in 1986 the Common European Act was passed, which proclaims protection of the natural environment and improvement of its quality, and optimum management of natural resources as the main objectives of environmental policy. Directives adopted by the EU Council of Ministers have become fundamental legal instruments of environmental policy, establishing common standards of environmental quality, waste discharge and waste treatment.

In 1972, *in the USA*, the Law on Marine Environment Conservation, Marine Reserved Areas and Marine Research was passed, and in 1997 a whole set of special administrative acts were passed pertaining to environment conservation in oil and gas bearing zones of Alaska, where intense exploration and development of oil and gas fields is underway.

In the USA, problems of marine environment conservation are in the sphere of competence of the Marine Environment Quality Standard Council (an advisory body to the US President) and the Environment Protection Agency (EPA). Regional plans on elimination of oil spills, aimed at preventing oil penetration in biologically sensitive and ecologically valuable areas have been elaborated. In most of the US coastal states, commissions and associations exist to control sea water conditions. Together with the Federal Coast Guard, they carry out measures to prevent oil spills and the penetration of other pollutants into the aquatic environment. Since the beginning of the 1950s, when the Act on Continental Shelf

Development was passed, more than a dozen money-consuming Federal nature conservation programs relating to oil production in Arctic seas have been carried out.

In 1982, *in Italy* the so-called "Regulation 979" was adopted. This was a first attempt to protect sea areas and coastal zones against pollution [109], the notion of "marine environment" being understood to include all the water in the given sea basin together with the sea bottom, shoreline, flora and fauna. In order to implement this regulation, a general plan was to have been prepared "to protect the sea and its shores against contamination and to preserve the marine environment" with the assistance of the Ministry for Natural Environment and Ministry of Marine Trade of Italy. However, ten years after this regulation was adopted, the plan had not been prepared, owing to the lack of coordination and cooperation between various governmental and public bodies, and to excessive bureaucracy and lack of financial support. Recently, during the preparation of a ten-year project on marine environment conservation, the necessity of drafting such a plan was once again emphasized.

In China, a law on marine environment conservation was also passed, because the problem of natural resources management and protection, especially in estuaries, bays, ports and coastal industrial centers, has become acute on account of grave environmental pollution.

In 1991, the Joint Nature Conservation Committee was set up *in England, Scotland and Wales* [110]. Measures for the improvement of the natural conditions of coastal waters, in accordance with the EU Directive on Quality of Bathing Waters, fall within the responsibility of regional bodies that deal with water problems [111]. In October 1992, the British governmental environment protection body 'English Nature' established a special company to promote marine environment conservation.

In the opinion of Russian specialists, large-scale human interference in the established balance of nature should be carefully planned and thought through, and its possible consequences should be predicted for decades ahead in a process of elaborating an overall strategy for natural resources conservation. *In Russia*, the classification of natural resources of water areas and adjoining land areas will be carried out, and possible and optimum ways of managing these resources will be outlined, taking account of environmental conditions and possible measures to restrict harmful human impact [112].

In The Netherlands, the problems of protecting valuable coastal ecosystems [113], developing their potential and preserving the diversity of juvenile and mature ecosystems in the whole coastal zone have been discussed. In 1985, the North Sea Water Quality Management Plan was established to preserve (and in some places achieve) the required level of water quality, especially in the near-shore zones, in order to help preserve the unique properties of the sea basin for a long time, including the protection of individual types of biological resources, restoration of marine ecosystems and prevention of disastrous consequences of sea water contamination [38]. Information submitted to the Netherlands Parliament forms the basis for legislating appropriate national laws and regulations.

In Australia and Great Britain, regulation of the coastal area again aims to conserve marine ecosystems and to improve the existing natural conditions, bearing in mind the social dimensions of the problem [114]. In the coastal regions of Great Britain, special attention is paid to the problems of protecting flora and fauna against harmful consequences of environment contamination, and the problems of preserving partially modified ecosystems and improving environmental conditions in general [115].

All this testifies to the great attention now paid by most countries that have access to the sea to marine environment conservation. Thus, the need for correct ecologonomic estimation of the nature conservation measures to be implemented has become clear.

Uncontrolled human impact on the environment and the growing anthropogenic load on ecosystems caused by intensified economic activity result in disturbance of the capacity of marine ecosystems for self-restoration. Marine environment quality deterioration, in turn, affects the economic development of coastal regions. Clean ocean waters and coasts, and rational management and protection of marine natural resources in ways that maintain optimum economic development rates are essential to the functioning of the marine economy. Ecologonomics says that successful management of today's production sphere requires the integration of various techniques of natural biological resources management into a single methodology of ecologonomic system management.

The main objective of the current stage of development of the marine economy is the transition to marine natural resources management that strictly controls the anthropogenic load on ecosystems. This necessitates radical changes in approach to the solution of marine environment conservation problems, taking due account of the requirement that further economic development should not increase the anthropogenic load on ecosystems. Unharmonized development of the technical means of marine natural resources management, neglecting criteria of the optimum load on the marine environment, may result in the marine economy being developed according to the "open scheme" pattern at the beginning and the end of their technological cycles. This means that in the initial cycle of production, natural resources will be withdrawn and consumed, and in the final cycle (at the stage of finished products), untreated solid and liquid wastes will be discharged directly into the sea, because the resources withdrawn will not be utilized completely, and no closed production cycles or wasteless technologies will be employed to save marine resources and prevent contamination of the aquatic environment with the toxic pollutants discharged. Any technological or engineering innovation related to ocean resources management cannot be considered progressive if its application leads to deterioration of marine environment quality. Therefore, closed (recycling) systems must be introduced in production processes, and waste discharge should be restricted by limits that take into account the marine ecosystem's capacity for renewal.

Marine environment quality deterioration caused by human economic activity in the sea and in the coastal zone at first manifests itself locally (at the regional level) [116]. This justifies a regional approach to evaluating human economic impact on the marine environment. It goes without saying that, at present, production activities cannot be analyzed from the viewpoints of economics and technological progress only. The interaction between the production sphere and the marine environment necessitates the development and application of new ecologonomic criteria for estimating the production level and technologies employed, criteria that reflect the dynamics of marine ecosystem productivity and the economic efficiency of natural resources management and human labor in this sector of a national economy.

Thus, the following criteria should constitute the theoretical fundamentals of marine environment conservation:

- ecological capacity of the given industry (or enterprise);
- technogenic capacity of marine ecosystems;
- unification of requirements constraining the anthropogenic load on marine ecosystems;
- regional approach to the organization of marine environment conservation;
- improvement of economic relations in the sphere of marine environment conservation, based on the evaluation and economic stimulation of prudent marine natural resources management and protection.

Our concept of regional ecologonomic systems is based on exact data characterizing these systems. Methods for analyzing them should be based upon a complete set of economic and environmental parameters for the given region.

From the viewpoint of economic evaluation of marine environment conservation measures, it is relevant to analyze a set of ecologonomic parameters that reflect the effect of human economic activity on the marine environment.

The importance of preserving the standard quality of the marine environment is becoming an issue of ever-growing significance. However, to date, there has been no satisfactory matching between parameters of marine environment conservation and economic development parameters in any of the coastal countries.

At the same time, marine environment conservation can be reflected in parameters of economic development by two indices – damage and capital investment.

Economic damage caused by marine environment contamination is one of the most important parameters of the economic efficiency of nature conservation measures. When implementing such measures, it is worthwhile to estimate the ratio between the total value of capital investments and the value of prevented damage (giving an indication of the efficiency of nature conservation measures). In the section 3.3 we analyzed the procedures for determining two integrated indices – specific contamination of the marine environment and the ecological capacity of a particular branch of the marine economy.

The application of a system of comparative estimates in determining the ecological capacity of a certain economic objective can ensure that appropriate management decisions are made on the selection of environment conservation measures, reconstruction or modernization of a particular enterprise or a whole branch of industry, and priority of capital investments allocated for these purposes. Input data for calculating the value of the ecological capacity of an enterprise can be obtained from statistical reports (quantities of finished products and discharged wastes).

The integrated parameters described earlier are evaluated as the costs required to restore the standard quality of the marine environment:

$$U = U_{vn} \cdot Z \tag{3.17}$$

where

U_{vn} is the unit value of damage, equal to the value of compensation costs for restoring the required marine environment quality (EUR/ton);

Z is the quantity of waste detoxicated by natural means or artificially (tons).

The economic estimation can also be carried out in terms of the required capital expenses (K) for nature conservation measures:

$$K = K_{vn} \cdot Z \tag{3.18}$$

where

K_{vn} is the minimum unit capital expenses for the removal of a particular pollutant (EUR/ton).

The effect of implementing nature conservation measures (D),expressed as the value of prevented damage, can be determined, taking into account the time factor, with the following formula:

$$D = e \cdot \sum_{t=0}^{t'} F(t) \cdot \Delta t \tag{3.19}$$

where

e is the profit during the first year of implementation of nature conservation measures;

$F(t)$ is a prognostic dimensionless function of time, reflecting the dynamics and discounting of a certain effect;

t' is the assessed period of the effect of capital investments on marine environment conservation measures; the value $t = 0$ corresponds to the first year of implementation of a certain environment conservation measure, for which $F(t) = 1$.

The character of changes in this prognostic function $F(t)$ depends on the character of the measures implemented, and on the adopted strategy of natural resources management.

The great significance of marine environment conservation and its complicated nature reinforce the necessity of establishing regional environmental programs, and this is confirmed by the practical experience of many coastal countries. These programs should envisage establishing a set of normative parameters for ecologonomic systems functioning in the given region, and also parameters governing the interaction between the ecological and economic subsystems within the ecologonomic system in question. In addition it is necessary to develop and introduce wasteless and closed-cycle technologies and improve the overall management of ecologonomic systems at the regional level.

The implementation of a regional environmental program not only promotes increased efficiency of marine economy development in the particular region, but also stimulates the economic development of the coastal zone. In addition, the implementation of such a program will allow for:

- creation of a regional system of marine natural resources management;
- selection of optimum scenarios of marine environment conservation in the given region;
- determination of maximum permissible levels of marine environment contamination;
- elaboration of the fundamentals of rational organization of environment conservation activity in the region;
- establishment of a system of standards to regulate the development of the marine economy and of other industries in the coastal region;
- creation of a system of automated ecological and economic data collection, processing and presentation for decision making within the ecologonomic system of the given region.

These aspects of regional economic development taking account of marine environment conservation might become the basis for a long-term strategy of natural resources management in the region under consideration.

However, when solving problems of economic evaluation of environment conservation measures, it is very important to determine the cost efficiency of such measures. As an initial assumption for determining the economic efficiency of environmental expenses, we suggest use of the concept of their absolute and relative efficiency, expressed as unit costs of the various scenarios of marine natural resources management.

Estimation of the *overall* efficiency of environment conservation measures is a strategic task, because the possibility of obtaining a certain economic effect is analyzed and evaluated for a particular scenario of natural resources management. For this, an international forecast of ocean resources management may be used, as well as various economic forecasts, and forecasts of scientific and technological progress.

Estimation of the *comparative* efficiency of nature conservation measures is usually required for solving tactical problems of marine natural resources management. We consider it impossible to manage natural resources rationally until a scientifically substantiated scenario of marine environment conservation has been elaborated.

The efficiency of environmental costs not only affects the planning, organization and technologies of marine natural resources management, but also the directions of research in this field, because the costs determine the economic expediency of each scenario of marine natural resources management.

The overall and comparative efficiency of the costs of nature conservation measures are closely related to the calculation of damage caused by marine environment contamination, forecasts of economic development of certain enterprises and industries using marine natural resources, and economic evaluation of these resources. The interdependence between these categories allows us to consider economic efficiency as a generalized criterion of rational management of marine natural resources.

Prevented damage is the main type of damage to be calculated in the process of estimating the economic efficiency of nature conservation measures. It can be presented as:

$$a = P_1 - P_2 \tag{3.20}$$

where

P_1 and P_2 are the costs of production (including related services), as affected by the state of the marine environment before and after, respectively, the implementation of particular nature conservation measures.

Note that the diversity of approaches to the evaluation of damage is not reflected by equation (3.19) alone. There is, for example, a so-called "method of calculating the profit", for determining the profit of a certain enterprise, using the marine resources before and after the implementation of particular nature conservation measures. This profit can be calculated as:

$$a = Q_2(B_2 - C_2) - Q_1(B_1 - C_1) \tag{3.21}$$

where

Q_1 and Q_2 denote the amount of the same or similar products whose production is related to the use of marine natural resources before and after, respectively, the implementation of the nature conservation measures under review;

C_1, C_2, B_1, B_2 denote the cost price of the same or similar products whose production is related to the use of marine natural resources before and after, respectively, the implementation of the nature conservation measures under review.

As a result of the implementation of particular nature conservation measures, the cost price of the product changes. In equation (3.22) this change is shown as ΔC. If prevention of marine environment contamination allowed an increase in the scale of resources production, then we should take into account the corresponding expenses for such an increase in resources production:

$$a = Q_2(C_1 - C_2) = Q_2 \cdot \Delta C \qquad (3.22)$$

The cost efficiency of nature conservation measures often turns out to be "implicit" (concealed), especially for non-material production. The longer the time for which the forecast is made, the greater will be the degree of implicitness of such efficiency.

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Chapter 4

ECOLOGONOMIC EVALUATION OF MARINE ECOSYSTEMS

4.1. BALANCED STATE OF MARINE ECOSYSTEMS

Any marine ecosystem is capable of producing organic matter and decomposing natural and artificial substances (i.e. it possesses a self-purification capacity). Maintaining the ecological balance in the marine environment is the main condition of both effective economic development and normal functioning of marine ecosystems. Thus, the balanced state of the marine ecosystem can be regarded as an indication of harmonious interaction between human economic activity and the marine environment. Conversely, disturbance of the ecological balance may be regarded as the main evidence of negative anthropogenic impact on the marine ecosystem.

The constantly increasing anthropogenic load on the aquatic environment entails degradation of marine ecosystems in individual sea basins, radical changes in the structure and functioning of marine biocenoses, in combination with possible negative effects of geochemical factors and sanitary-hygienic consequences. Natural cycles of carbon, nitrogen, sulfur and other elements are disturbed, and the heat, moisture and gas circulation between the ocean and atmosphere changes [117]. However, most significantly, human impact leads to decreased biological productivity and the exclusion of certain types of hydrobionts from production processes.

Under such conditions, preservation of the balanced state of marine ecosystems is a necessary prerequisite for improving the condition of the aquatic environment and optimizing the development of the marine economy. The ecological balance is itself a dynamic process, because the ratio between its components is always changing.

The problems of balance and stability in nature are very complicated and variable. In general, their solution may be reduced to fitting economic activity into natural processes [118]. The balanced state of marine ecosystems should be regarded as the "guarantor" of stable economic development of coastal regions.

The internal balance of biocenoses, including the great variety of different organisms which constitute the so-called "food chains" (from the simplest producers to predators), is the regulator of marine ecosystem development. Another regulatory factor is the absence or presence of certain ecological niches. Thus, the ecological balance is directly determined by the number and ratio of different types of organisms in the biocenosis of the sea basin in question; a significant increase or decrease in the population of certain species in the biocenosis of the sea basin disturbs the balance of its ecosystem.

The ecological balance of the marine ecosystem is also governed by the conditions of the given sea basin, its geographical position, climatic features and hydrological parameters [119].

Some time after the state of the marine environment has changed, a new dynamic ecological balance is established, which is preserved until the beginning of another new stage of economic activity in the sea basin in question, which, in turn, will lead to another change in this ecological balance. Note that the newly established ecological balance may not always be optimum for the biological resources of the ecosystem under consideration.

Before the beginning of noticeable human impact on the marine environment, the balanced state of the marine ecosystems (including the preservation of species diversity and populations) was maintained by mechanisms of natural self-regulation. Any disturbance in the ecological balance acted like a "flip-flop", setting this mechanism into effect, and as a result establishing a new balanced state.

The evolution of marine organisms, as a rule, occurred only within certain time intervals, and did not affect all intermediate populations, although some generations were affected to a certain extent, depending mainly on the size of their population. However, the mechanism of natural self-regulation came into operation only when certain populations increased disastrously, resulting in not only quantitative but also qualitative changes.

If we consider an ecosystem as a particular set, then it becomes evident that this set consists of a number of relationships, characterized by their own specific parameters (e.g. for trophic relationships such characteristic parameters are the quantity of energy and of biomass).

Natural self-regulation mechanisms and the relationships within marine ecosystems have not been thoroughly investigated and require special analysis of each individual case. Nevertheless, knowledge about such individual relationships forms the basis for calculating and forecasting changes in marine ecosystems caused by human economic activity, as well as by evolution itself.

Disturbance of the ecological balance in the marine ecosystem is most frequently the result of changes in the trend and intensity of processes occurring in it. Most often, these processes are accelerated, which may be caused by long-term or short-term impacts (say, anthropogenic impacts) and such acceleration may be harmful for living organisms.

Simulation modeling can be successfully used in studying natural relations in marine ecosystems. An estimation of the degree of human-induced disturbance in natural relationships, prediction of changes, evaluation of the character and scale of their consequences are all factors which serve as the basis for management and control of natural phenomena in the process of conscious transformation of nature by humans.

It is necessary to take into account the disturbance of the ecological balance resulting from the interaction between marine ecosystems themselves – a regular process of substance and energy exchange which takes place everywhere. This process causes the formation of marine ecosystems of varying composition and structure and varying resistance to changes in ambient conditions. The difference in the development rates of the interacting marine ecosystems, manifesting itself in different rates of changes in intra-system and inter-system relations, is as a rule an impetus to changes in the relationships between different ecosystems and the inter-system balance. In the long run, all this leads to the formation of certain feedback structures, i.e. reverse changes within the components of marine ecosystems, resulting in a chain of complex evolutionary changes where new relationships replace old ones, either gradually or abruptly.

In marine ecosystems, the rate of evolutionary processes plays a very important role. Changes in it are usually caused by large-scale global phenomena, such as marine transgression or regression, continental glaciation, etc. At present, under conditions of scientific and technological progress, the scale of human economic activity, having a complicated and diverse effect on marine ecosystems, is comparable to the scale of such natural global phenomena.

Human-induced increase or decrease in the rate of natural processes results in change in rates of evolutionary processes, causing acceleration or (more likely) deceleration in the development of marine ecosystems. Sometimes such deceleration in marine ecosystem development can bring about its partial or complete degradation. Every time a marine ecosystem is subject to any external impact, it undergoes restructuring. The occurrence of new ecosystems also becomes possible.

Analysis of the dynamics of interaction between marine ecosystems, their balanced state, stability, self-restoration capacity, and prediction of human-induced changes in their rate of evolution is important for the management of natural processes and creation of optimum ecosystems, simultaneously preserving their self-renewal capacity.

There are various approaches to investigating the balanced state of marine ecosystems. We must distinguish between the dynamics of the marine environment within a certain period of time, when sometimes we can observe relative stability and balance in marine ecosystems, and the dynamics of long-term evolutionary changes. The latter is of a global character and extremely complicated, leading to changes in the World Ocean ecosystem as a whole and in the ecosystems of individual sea basins.

The discrepancy between the relative stability of certain components of the marine ecosystem and the constant changes in these components is the principal pattern in the development of all marine organisms. Unusual situations occur from time to time during the process of ecosystem development, such contradictions being the stimulus for further development and change in marine ecosystems.

The ocean ecosystem, which is in a state of dynamic balance, is a relatively stable system, capable of self-restoration. This state can be disturbed by either large-scale changes (human-induced or otherwise) in ambient conditions, violating previously established connections between its components, or by gradual increase in internal discrepancies, leading to all kinds of changes, having various time ranges, modifying the ecosystem and making it ever more complicated. In all such cases time is a very important development factor which must not be neglected.

A *stable balance of the marine ecosystem* is characterized by quick restoration of previously existing relationships between its components. Such restoration is called self-regulation or adaptation. It depends directly on the properties of the ecosystem in question and the parameters of the impacts disturbing it.

An *unstable balance of the marine ecosystem* is characterized by a situation where even under small-scale disturbances in the existing relationships a whole chain of irreversible consequences begin to manifest themselves, making a return (either complete or partial) to the initial state impossible. We can therefore say that unstable marine ecosystems require permanent active human interference in their process of evolution.

Thus far, we have tried to analyze marine ecosystems from the standpoint of their genesis and forms, and to determine stages in their development. It is now necessary to consider the energetic essence of this development, determine the intensity of processes occurring in marine ecosystems, and demonstrate the dynamics of all the relevant phenomena in the conditions of the given sea basin during a certain period of time. Such an approach could become a basis for purposeful transformation of the marine environment and regulation of natural processes by humans.

Thus, the *ecological balance* of the marine ecosystem is understood as the preservation of its self-renewal capacity without any significant degradation of any of its components.

In determining such a balance we analyze the degree of change in all or some of its parameters under the effect of a disturbing impact; in this case, therefore, the notion of "balance" has the same meaning as "stability". The balanced state of the marine ecosystem is characterized by:

- absence of significant changes;
- persistence, determining the survival of its living organisms;
- sluggishness;
- resistance;
- resilience, showing how quickly the ecosystem can return to its initial (background) state.

The diversity of the marine ecosystem is often considered to be a measure of its stability. This is explained by a high degree of correlation between variety and stability.

Due to natural self-purification processes, enormous amounts of pollutants are removed from the marine environment; thus its preservation is ensured. In the marine ecosystem, a whole range of biotic and abiotic processes have formed, which provide the dynamic balance of the marine ecosystem.

Distinguishing the boundaries of marine ecosystems is an important step in the determination of their balanced state. However, the diversity of physical, chemical and biological processes and the peculiarities of individual ecosystems hamper the solution of this problem [120].

At present at least three types of marine ecosystems can be identified:

(1) Closed (e.g. ecosystems of bays and lagoons). Restricted water circulation and rather clear-cut borderlines are typical. In some cases, for the sake of simplicity, the so-called "inland seas" (e.g. the Caspian Sea, Azov Sea, etc.) be regarded as a model of such ecosystems.

(2) Half-closed (e.g. ecosystems of river mouths and estuaries). Such ecosystems are located in the zone of mixing of different waters. Mathematical models taking account of the effect of tidal currents can be used to describe them.

(3) Open, i.e. ecosystems whose boundaries are determined by a concrete ecological or hydrological situation, and by the spatial distribution of pollutants.

From the viewpoint of hydrodynamics, the boundary of the marine ecosystem can be outlined on the basis of bottom topography, current fields and the spatial distribution of certain physical parameters of the marine environment in the given sea basin. Where there is a lack of hydrological and/or hydrodynamic information, marine ecosystem boundaries are determined on the basis of the geographical parameters of the region under review, with due account taken of seasonal changes in the marine ecosystem itself.

When distinguishing the so-called "impact zones", the spatial parameters of the following process are very important:

- biological processes (including microbiological ones) that decelerate or accelerate pollutant transport within the ecosystem;
- physicochemical processes (sedimentation, dissolution, adsorption, desorption) that determine the resident time of pollutants in sea water;
- biochemical processes (oxidation and reduction, photosynthesis, etc.) that can accelerate or decelerate the degradation of some organic pollutants.

Determination of the marine ecosystem's balanced state is the final stage of its identification (outlining its boundaries, calculating the number and ratio of particular individuals, species and populations in its biomass, determining the distribution of its components). Thus, before determining the balanced state of the marine ecosystem, we should thoroughly analyze it in order to have an idea of it as the integral object of our investigation. Then we must outline its boundaries, taking into account the physicochemical, biological and biochemical processes described earlier. Next we must match the zones of pollution with the boundaries of the marine ecosystem.

Generally, the balanced state of the marine ecosystem is observed under a condition of equality of two effects:

$$E_i = E_r \tag{4.1}$$

where

E_i is the impact effect;

E_r is the response effect.

In the marine ecosystem, harmful anthropogenic impact causes the manifestation of various physical, chemical and biochemical processes, contributing to the triggering of adaptation mechanisms whose actions are aimed at eliminating negative consequences of such harmful impact. Thus, the marine ecosystem's balanced state can also be defined as its capacity of self-defense against anthropogenic or any other impact (based on the above processes) in combination with the preservation of its self-renewal capacity.

The balanced state of the marine ecosystem is also characterized by its capacity for dynamic accumulation and active removal of toxic substances that have found their way into it, while preserving, at the same time, all its other capacities and functions. Such a balance depends on numerous natural and anthropogenic factors, such as current velocities, water temperature, salinity and transparency, structure, composition and functioning of biota, as well as on the chemical and physical properties of pollutants entering the ecosystem.

The numerous natural factors determining the water self-purification capacity can be reduced to a few most important processes: hydrodynamic transport of pollutants; biological transformation of pollutants (including microbial oxidation); and certain chemical and physical transformations [121].

As was mentioned earlier, marine ecosystems that remain unchanged for a long time possess a certain "internal capacity" to resist disturbing impacts such as pollution. This capacity of marine ecosystems is called "resistance". It is useful to determine this property, so that it can be measured and so that we can compare various marine ecosystems according to this parameter.

Let us assume that we have a full and adequate model of the marine ecosystem. The resistance (stability) of this ecosystem can be determined by analyzing our model with the help of traditional methods of the theory of stability: the ecosystem is stable if its trajectory in phase space remains within the limits of an assigned area under the conditions of certain ultimate disturbances varying within a broad range. In practice, however, this method of studying the model is impossible because it is extremely difficult to develop a really good model of the system. Here we return to the problems of simulation modeling [32].

The stability of natural ecosystems involved in large-scale economic development projects restricts the scope for us to experiment with them. Under such conditions, we develop and investigate simulation models describing the interaction between human economic activity and the environment.

Taking into account the fact that no model can be an exact representation of a real object (it can only reflect our knowledge about it), it is not realistic for us to expect to be able to develop an efficient model (or a system of models) that would help us to easily and quickly implement a complicated task such as the investigation of processes of interaction between economy and natural environment in a given region or on the planet as a whole. Nevertheless, even a model that is not so perfect can help us solve certain problems arising at the initial stage of research which could not easily be solved using other methods. This is particularly true for the solution of ecologonomic problems because the success of interdisciplinary research is ensured not only by the possibility of using the results of both economic and ecological investigation; it is largely determined by the degree of combination of their results. In a process of model development, the main requirements for input data are specified, and relations between various aspects of the problem to be investigated are specified.

Discussions of the model, and results obtained with its help, by both economists and ecologists bring about certain prerequisites for the solution of problems discussed in this part of the book, which, in the long run, will enable us to obtain more accurate results on the basis of a better model (in terms of its accuracy, adequacy and reliability). Thus, the model is necessary to all the stages of solving the given problem.

Today, there are many scientific publications dealing with the development and investigation of mathematical models of ecological systems, pollutant spreading in the marine environment, etc.

From the viewpoint of modern economics, the balanced state of marine ecosystems can be measured and expressed in monetary units. The evaluation of such a balanced state is an integral part of evaluating marine ecosystems as a whole. Any attempt to use the marine environment for economic development should necessarily envisage measures aimed at the preservation of marine ecosystems' balanced state.

4.2. EVALUATION OF HUMAN-INDUCED CHANGES IN THE STATE OF MARINE ECOSYSTEMS

In analyzing the balanced state of marine ecosystems from the viewpoint of permissible anthropogenic load, we take the assumption that, if such anthropogenic impact exceeds a certain level, it can lead to disturbance of the ecological balance in the marine environment. It is thus essential to determine the permissible level of such impact.

Anthropogenic impact is any type of human economic activity that affects the natural environment. Such activity is characterized by certain anthropic factors, such as various physical fields, e.g. pollution fields, fields of pollutant concentrations, radioactive contamination, etc. [122]. *Anthropogenic load* can be defined as a measure of the direct or indirect human impact on nature through a process of economic activity.

In order to substantiate permissible levels of human impact and anthropogenic load, modern science suggests analyzing the impact of different factors on marine ecosystems. We must then identify the critical factors and most sensitive elements of the ecosystems, and estimate the possible damage that might be caused by such human impact. Then, taking into account the results of previous investigations, we should determine the value of the permissible load for individual organisms, their populations and communities, and for the whole ecosystem under review. *Permissible anthropogenic load* is defined as the load that does not lead to undesirable changes in marine organisms and deterioration of marine environment quality. The quantitative measure of such load is the maximum permissible concentration of pollutants (MPC), determined using the toxicological or the biochemical method.

The biochemical method is used to determine, for instance, the MPC of heavy metals in sea water which are, on the one hand, regarded as environmental pollutants, and, on the other hand (at low concentrations), as natural components of sea water. Thus there is a natural, "evolutionary-determined" limit of heavy metal concentration in the marine environment, the value of which is adopted as the MPC for these substances. So it is clear that the essence of the biochemical method is the determination of optimum values of certain pollutants' concentrations in the marine environment, these concentrations being adopted as the MPC.

In practice, the MPC values are often calculated using a simulation model of the ecosystem. In this case, the reliability of the result obtained will depend on the accuracy and reliability of the model, reflecting the state of the marine ecosystem under consideration. The development of such a model, which should in addition possess certain prognostic abilities, requires a considerable amount of input data, which can be obtained by observation and/or on the basis of preliminary studies.

The toxicological method is based on the analysis of the peculiarities of a particular marine ecosystem. This involves the estimation of human impact on marine ecosystems in terms of one selected component of this ecosystem, based on the assumption that the condition of this component (unit or process) reflects well-being of the ecosystem as a whole. The critical values of pollutant concentrations are determined from the estimated effect of pollutants on the selected component; the laboratory conditions under which the MPC values for the pollutants in question are determined should be similar (to the greatest possible extent) to the natural conditions in the marine ecosystems investigated. If this is so, and if the component is selected correctly, it is possible to determine the MPC exactly.

The choice of method for determining the MPC depends on our particular objective. The biological method is preferable for determining the balanced state of the marine ecosystem, because the ecosystem can be represented by a simulation model. The toxicological method is traditionally used as a test method.

If we use the second method as the basic one, we should bear in mind that different components of marine biota and different ecological processes have differing sensitivity to pollutants. For this reason, when selecting a representative unit of the marine ecosystem, we should choose an object or process that would possess maximum sensitivity to the pollutants under review, and at the same time have an appreciable effect on the ecosystem as a whole. In order to substantiate the selection of such a unit, it is necessary to have sufficient information on the primary production and destruction of organic matter, the typical biomass of the main types of hydrobionts, and the state of the dominant species of marine organisms.

The biomass of the marine ecosystem, which depends mainly on the primary production of organic matter, is a component that meets the above requirements. At the same time, biomass of the marine ecosystem and organic matter production are the main elements of the marine environment biotic balance. Bearing this in mind, we can deduce a coefficient K_k, which is the ratio of the marine ecosystem biomass B_e to the production of primary organic matter P_{or}:

$$K_k = B_e / P_{or} \tag{4.2}$$

Sometimes, as a characteristic unit of the marine ecosystem, certain fish species can be chosen whose presence in the given sea basin characterizes the "fishery value" of the basin.

In determining the balanced state of the marine ecosystem, we must distinguish two states: the background state and the state of ecological stress.

The toxicological method is traditionally used in establishing MPC values for marine ecosystems. It is based on the result of experimental differentiation between toxic (threshold) values of pollutant concentrations for various types and species of hydrobionts at different stages of their development, on the one hand, and on "harmless" pollutants' concentrations, on the other hand. In this case, the *toxic concentration* is defined as the pollutant concentration at which relative values of survival, fecundity, growth and biological productivity of marine organisms are less than the values of the same parameters determined in test experiments, by more than 50%. The pollutant concentration at which relative values of the aforesaid parameters are decreased by less than 25% compared with the values of the same parameters obtained in test experiments is defined as the *permissible concentration.* That is: the concentration preserving the balanced state of the marine ecosystem with the main parameters not deviating by more than $\pm 25\%$.

Ecological and sanitary-hygienic approaches to the elaboration of marine environment quality standards differ greatly from each other. The sanitary-hygienic approach is based on the assumption of preventing any harmful impact, even to an individual organism. In contrast, the main criterion of ecological standardization is the preservation of the balanced state of the marine ecosystem.

When elaborating standards for the impact on a particular marine ecosystem, we must first determine the value of a critical impact resulting in the destruction of the given ecosystem. Then, based on the available results of relevant scientific studies, we calculate the value of the "stability" ("reserve") coefficient (K_a), which is a ratio of the permissible impact I_p to the critical impact I_{cr} :

$$K_a = I_p / I_{cr} \tag{4.3}$$

Substantiating ecological standards necessitates accounting for differences in the response of different populations of the same ecosystem to the same impact; effects of chemical and biological accumulation of pollutants (in food chains) should also be taken into account, as well as transformation of substances into more toxic compounds as a result of migration. These processes can be decisive in revealing representative units of the marine ecosystems and determining the critical value of anthropogenic load on these ecosystems.

Ecological standardization should be implemented taking into account the complicated processes occurring in marine ecosystems, the trajectories of pollutants' migration and the way they enter the marine ecosystem in question.

The achievements of modern ecology in classifying various states of marine ecosystems and the capacity of modern computers to process great amounts of information create new possibilities for studying the role of various anthropogenic factors in the changes of ecological state of various natural entities. It is today possible to investigate the direct impact of anthropogenic and other related factors on the marine ecosystem as a whole, and not only its individual components.

In order to evaluate anthropogenic ecological stress and the balanced state of marine ecosystems, we can use data from hydrobiological monitoring, which should be carried out in every sea basin.

Analysis of a set of impacts and singling out the most important of them are very complicated statistical problems. Regression analysis is therefore used for multifactor analysis of a marine ecosystem.

The state of dynamic balance of the ecosystem can be presented as its change (to a certain limit) under the impact of one or several factors.

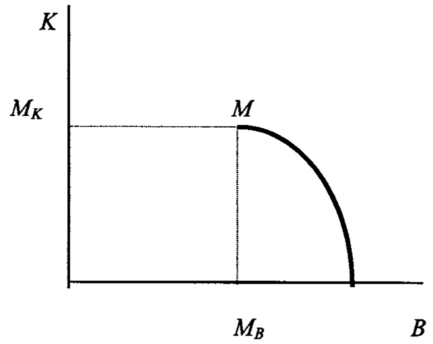

Figure 4.1. Graphic representation of the balanced state of the marine ecosystem.

The curve in Figure 4.1 illustrates the balanced state of the ecosystem. A certain value of a pollutant concentration can be defined as the "ecologically permissible concentration" (EPC), differing from "maximum permissible concentration" (MPC). It is determined as follows. Let us put values of the ecosystem biomass along axis B and values of a pollutant concentration along axis K. Point M, and its projection on axis B (M_B), is the EPC value.

The technique of calculating the EPC is quite simple. First we analyze the ecological state of the given sea basin, i.e. the balanced state of its ecosystem which can be attained under the given level of contamination. For this we determine the components of the ecosystem and the limit within which the balanced state of this ecosystem is preserved under the given level of contamination.

The most difficult thing here is to analyze factors that cause the conditions of the marine ecosystem to deteriorate, because ecosystems differ in their parameters (types and species of animals and plants, ecological niches, etc.), which makes it difficult to single out factors that improve or damage it.

Some factors can affect the ecological balance while remaining within the limits of the curve in Figure 4.1. The main index of changes, however, in the ecological balance of the marine environment is the biomass of the ecosystem. The formal criterion of singling out a particular factor as impairing the quality of the marine environment is that it exceeds certain limits (i.e. values beyond the curve).

Analyzing the ecological conditions in the Azov Sea basin with the help of the above-mentioned criteria, we identified 13 factors (depending on the season of the year) and determined EPC values for each of them (Table 4.1).

As was mentioned earlier, it is important to distinguish the terms "ecologically permissible concentration" (EPC) and "maximum permissible concentration" (MPC). At present the MPC is the main criterion for estimating the degree of pollution of various ecosystems. But the MPC values for many pollutants were obtained using laboratory test objects, and extrapolation of the results of such experimental MPC determination to natural conditions is not always justified. In our opinion, the EPC together with the MPC should be regarded as the criterion of the ecosystem's balanced state, the difference between the EPC and MPC being that the EPC serves both as a criterion for identifying pollution factors and represents the natural conditions of ecosystems better than the MPC. In many cases, the MPC and EPC values may be different for the same element in different sea basins.

Table 4.1. Factors affecting the Azov Sea basin ecosystem and values of their EPC.

Factors	Ecological permissible concentration, mg/litre
Nitrogen peroxide	0.048
Phenols	0.005
Nitrates	0.18
Nitrites	2.33
Iron	0.05
Copper	0.006
Oil and oil products	0.15
Synthetic surfactants	0.03
BOD_5	3.79
Chromium	0.005
Pesticides	0.56
COD	7.18
Zinc	0.019
Arsenic	0.007

Reprinted from: A.V. Souvorov, E.V. Fidirko, *Prediction of Ecological–Economic Interaction in the Region.* The Uzbek State University, Samarkand, 1987, pp. 59–60.

Further investigation of the problem of marine environment conditions and the state of marine ecosystems on the basis of EPC criteria (obtaining and analyzing the EPC and MPC values for as many sea basins as possible), will allow us to determine the EPC for the ecosystem of the whole World Ocean.

The EPC criterion can also be applied in forecasting the state of marine ecosystems according to available values of anthropogenic load. In this case, it should be taken into account that the interaction of various external factors can modify the pollution effect, whereas determination of MPC and EPC values necessitates the comparison of different sea basins according to the effect of one single factor.

Intensification of the effect of toxic substances on marine ecosystems leads first to an abrupt decrease in the number of species sensitive to it, and then to a reduction in the total bioproductivity of the given ecosystem. If anthropogenic load remains unchanged, certain types of organisms die. After the anthropogenic effect is eliminated, two variants of the further development of the ecosystem become possible:

- restoration of the previously existing community and its population and structure;
- irreversible changes in the biotic component of the marine environment.

When the concentration of a certain pollutant achieves the M value in Figure 4.1, irreversible changes begin to manifest themselves in the ecosystem, irrespective of whether the concentration of the pollutant that has caused such changes grows or remains constant. We shall observe a reduction in the number of hydrobionts and in the biomass value, i.e. $M_B \to 0$.

At present, the M value is determined mainly on the basis of changes in the quantity of hydrobionts, and on the basis of manifestations of negative morphological, biochemical and genetic consequences of the given anthropogenic impact.

Determination of critical concentration values for individual pollutants is hampered by the great variability of their toxicity parameters, depending on the ecological situation in the sea basin. The effect of pollutants on hydrobionts is determined by sea water temperature, transparency and salinity, sea currents, species composition and the physiological state of plankton community, as well as by pollutant migration and transformation in the sea basin.

Specifying the position of point M on axes B and K (M_B and M_K, respectively) is an important element of forecasting the ecological conditions of the given sea basin. It is therefore important to estimate the effect of such widely spread pollutants as heavy metals and organic compounds on the selected unit of the given ecosystem [123].

Evaluation of marine ecosystems can demonstrate their unfavourable conditions, specify the reasons for such a poor state, and outline measures that can help improve the situation. In contrast, such evaluation can help us identify favourable conditions of marine ecosystems (short term or long term) and the ecosystem properties that will maintain such conditions. All this can provide for more efficient use of their ecological reserves [124].

Thus, in order to evaluate the state of a marine ecosystem, taking into account human-induced changes occurring within it, it is necessary to:

(1) calculate the possible damage that may be caused to the marine ecosystem as a result of natural or anthropogenic impacts on it;

(2) estimate the natural potential (or reserve) of the ecosystem which could help this system overcome the aforementioned negative effects. For this we must find the value of the maximum permissible load on the environment and the ecological stability of the marine ecosystem.

Unfavourable consequences can occur (at varying degrees of probability) even under conditions of insignificant deviation of the marine ecosystem's state from the optimum. A 5–10% probability of irreversible changes occurring in the ecosystem is considered to be critical.

Let us now introduce a certain function of the marine ecosystem's state which characterizes its biological productivity and the rate of substance exchange processes within it. Such a function $\eta(R, t)$, characterizing both temporal and spatial variability, can be analyzed for any marine ecosystem within the limits adopted for it.

When examining this function, we determine its critical value η_{crit} and maximum permissible value η_{mp}. These values may differ from or coincide with each other, depending on the situation.

It is evident that any deviation of the conditions of the n-th marine ecosystem from its initial (background) state due to the effect of external factors (A_n) is determined by the intensity of these factors. Under the effect of these factors, the state of the ecosystem changes from the initial state (background or already modified somewhat from the background state), characterized by function η_0, to a new (modified) state, characterized by function η_φ:

$$\eta_\varphi = A_n \cdot \eta_0 \qquad (4.4)$$

Ecological damage is caused by deviations in the marine ecosystem's functioning, which may be irreversible or reversible.

The difference between the actual and critical state of the marine ecosystem is called the *ecological potential* (or "ecological reserve") *of the ecosystem*. In this respect, it is expedient to go back to the problem of the economic evaluation of damage caused to the marine ecosystem by aquatic environment contamination. The suggested approach to the solution of this problem is based on several assumptions:

(1) damage incurred by the given marine ecosystem is a results of changes in the marine ecosystem's state caused by impacts exceeding a certain admissible level;

(2) the marine ecosystem responds to all these impacts as if these impacts affected it as a single combined impact;

(3) different marine ecosystems have different response to the same impact (or impacts);

(4) in spite of a huge variety of possible changes in the state of the marine ecosystem which may be caused by aquatic environment contamination, we can estimate, quantitatively, only the part of the damage incurred due to changes in the biomass and productivity values of the given ecosystem.

All these assumptions allow us to implement quantitative evaluation of the damage caused to individual marine ecosystems on the basis of empirical data of the dose–effect type.

As was mentioned earlier, anthropogenic impact on marine ecosystems which exceeds certain limits (EPC) can cause ecological stress. Any stress decreases the species diversity of the ecosystem's plant and animal communities, which is directly related to the resistance of these communities. The higher the resistance, the higher the species diversity of the community in question. To describe the species diversity of a given community, we need detailed information on each species (the number of individuals, their biomass, morphological characteristics, etc.), and on the exact number of organisms in the given ecosystem. Owing to the fact that organisms belonging to different trophic levels possess differing sensitivity to harmful impacts, it is necessary to analyze each trophic level separately in order to get a better idea of the species diversity of the analyzed community of marine organisms.

Out of the great number of species at each trophic level, only some of them are widely distributed and have a high level of statistical significance (such species are regarded as *dominant species*), whereas other species are more rare. The structure of the marine ecosystem is determined by dominant species, and its species diversity is determined by numerous rare species (with a low level of statistical significance).

At present, there are two widely used indices of the species diversity of plant and animal communities [79]. The first one is the Sympson index, determined as:

$$D(a) = 1 - \sum_{1}^{a} p_1 \qquad (4.5)$$

The second one is the Shannon index, determined as:

$$H(n) = -\sum_{1}^{n} p_1 \log_2 p_1 \qquad (4.6)$$

Both indices have maximum values at the same level of significance for all the species of the given trophic level ($p_1 = 1/n$ for all values of n):

$$\max(D) = (n-1)/n \qquad (4.7)$$

$$\max(H) = \log_2 n \qquad (4.8)$$

If a certain species dominates in the community, its significance tends to 1, while the significance of other species tends to zero. If one species is dominant, the values of both the Sympson and Shannon indices tend to zero.

Analysis of the Sympson index value for numerous different communities has shown that for marine ecosystems having no intense inflow of energy and biogenic substances from outside, which depend upon the consumption and further transformation of solar energy under stable environmental conditions, the value of the Sympson index (D) varies from 0.70 to 0.85. Low species diversity (D varying from 0.05 to 0.2) is observed for communities that are either actively regulated by humans or have considerable inflow of biogenic substances and solar energy from outside (the latter being explained by certain natural reasons). The average values of the Sympson index, varying from 0.2 to 0.6, testify to the fact that the analyzed community is not stable.

For most marine biological communities, the value of the Shannon index (H) exceeds 4. The decrease of H to 1–2 under the effect of unfavorable ambient factors testifies to appreciable degradation of the community in question.

The use of the Sympson and Shannon indices allows us to evaluate the risk of any harmful impact (including anthropogenic impacts) on the marine ecosystem, and the possible damage that may be caused by such impact.

It is more difficult to analyze structural changes in marine ecosystems that result from human impact, but we can do this for individual communities of the investigated marine ecosystem.

The structure of a marine biological community is formed by the energy flux passing through it. The composition of the community is determined by the number and significance of species included in it, whereas the structure of the same community is determined by the most significant interactions within it. The significance of interactions, in turn, is determined by the quantities of inflowing substances and energy transferred by this interaction within the community. Thus, the structure of the community is determined by the most significant interactions between the species that dominate it, whereas the *well-being of the community* can be defined (from the viewpoint of its structure) as the well-being of the species that are dominant at each trophic level within the community.

The well-being of the dominant species, in turn, is determined by the amount of energy inflowing to a certain trophic level which can be spent by the individuals belonging to these species (or, in other words, consumed by these species). From this point of view, the conclusion that can be made on the well-being of a certain community on the basis of the difference between the amount of energy inflowing to the i-th trophic level (E_i) and the amount of energy not spent by the individuals of the given trophic level on their own needs (P_i) seems to be the most trustworthy:

$$W_i = E_i - P_i \tag{4.9}$$

The amount of inflowing energy is determined on the basis of the food ratio or photosynthesis production parameters (U_i) and the amounts of substances and energy consumed by the organisms of the given community (AS_i). The value of (P_i) can be calculated as the total of energy and substances spent on transforming incoming energy and substances into a form suitable for consumption by the organisms (Y_i) and the amounts of substance and energy consumed by the organisms of higher trophic levels (R_i). Therefore, the well-being W of the organisms of the i-th trophic level at a certain moment of time t can be determined as

$$W_i(t) = U_i(t) + AS_i(t) - Y_i(t) - R_i(t) \qquad (4.10)$$

Further calculations of substance and energy transformations in the system of metabolic reactions within the community seem to be too complicated and, therefore, unsuitable for practical application. But the well-being function W_i (t) can be used for determining the degree of risk of a certain anthropogenic impact for the i-th type of marine organisms in the community.

Ecological evaluation of human-induced changes in the conditions of the marine ecosystem is relevant for economic evaluation of the consequences of such changes. This is the essence of the ecologonomic approach to the evaluation of marine ecosystems.

4.3. Prediction of Human-Induced Changes in the State of Marine Ecosystems

Among all branches of the marine economy, fishing, dealing directly with the production and processing of marine ecosystem resources, is the most ecologically vulnerable. It is fishing that marine environment contamination causes greatest damage to. This damage manifests itself in full or partial destruction of the economic mechanisms of production, processing and sale of fish and other sea products obtained from processing marine ecosystem resources.

However, the determination of the damage caused to marine ecosystems by contamination of the aquatic environment is significant not only for fishing, but also for other branches of the marine economy – all users and consumers of marine natural resources – because determination of damage facilitates scientifically substantiated elucidation of measures aimed to eliminate the harmful consequences of marine environment contamination. It is hardly possible to hope for sustained development of the marine economy if nature conservation measures (especially those related to the prevention of future damage) are neglected. The problems of economic evaluation of ecological damage caused by marine environment contamination were discussed in detail in Chapter 3. We can only emphasize that in developing methodological principles for estimating damage and its after-effects, the following issues should be paid special attention:

- determination of the degree of sea basin contamination and its effect on marine ecosystems;
- calculation of the value of damage in natural units and expression of the resulting estimates in monetary terms;
- evaluation of the total damage caused to fishing and other branches of the marine economy;
- evaluation (as accurate as possible) of compensatory expenses for the elimination or prevention of damage caused by marine environment contamination;
- determination of the economic efficiency of aforementioned expenses.

The forecasting of human-induced changes in the state of marine ecosystems should be based on current and historical data on marine environmental conditions, obtained from long-term observations and from research designed to reveal patterns in various natural processes, the migration and transformation of pollutants, their effect on marine environmental conditions and the state of marine ecosystems, and the response of marine biota to changes in environmental conditions [125].

In the first stage, it is important to predict variations in the intensity of pollution sources and other factors that affect the marine environment. The input data for such prediction can be taken from statistical reports on economic development in the given region.

In forecasting the state of marine ecosystems, we can either assume that the level of economic development will remain the same or take into account projections of the increasing scope of economic activity in the region, which will undoubtedly result in the intensification of pollution. In the latter case, measures that will be implemented to decrease the level of pollution should also be taken into consideration.

The first (or even zero) approximation in such forecasting is the forecasting of marine environment contamination, based on the assumed absence of pollution at a certain time in the past. Such an assumption allows us to take into account all the geophysical, geochemical and biological processes related to the migration and transformation of pollutants in the marine environment. Special attention should be paid to possible increases in the toxicity of pollutants.

The next stage of forecasting is the prediction of possible changes in marine ecosystems under the effect of the pollutants that already exist in the environment, and of other impacts, as well new pollutants and newly emerging factors affecting these ecosystems.

Human-induced changes in marine ecosystems can effect their components over a long period of time (especially if we consider genetic consequences), even if the additional external impact is decreased or even appears to cease completely.

Analysis of predicted states of marine ecosystems allows as to determine the problems of greatest priority, whose solution will require urgent measures against possible negative manifestations of marine environment contamination. It also helps us to outline and carry out preventative measures against negative factors and phenomena that have not yet manifested themselves (in addition to measures aimed at mitigating and/or eliminating negative consequences that are already evident). Prediction of the state of marine ecosystems is an important stage of sea water quality management.

At present, there are numerous empirical methods of forecasting. All of them are based on two approaches: *heuristic* (involving the use of the opinion of experts in the relevant field of knowledge), and *mathematical* (envisaging the use of statistical information available for the subject of forecasting).

Heuristic forecasting can be described as follows. There is a set of techniques based on the assumption that, as a result of analyzing the opinions of highly qualified specialists in a certain field of science or technology, it is possible to develop an adequate model (or pattern) of future development, taking into account structural and qualitative changes that could occur. These methods are called expert analysis methods. In addition to the experts' opinions, based on the generalization of their own practical experience, worldwide practice should not be neglected. All heuristic methods are based on the assumption that experts have practical wisdom in their own field of knowledge or practice.

Expert estimates used today can be divided into collective and individual estimates. Methods of individual expert estimates include estimates of the interview type and analytical expert estimates. Methods of collective expert estimates include commission methods, the method of comparative estimation, the Delphi method, etc.

Correct application of expert methods ensures better coordination of the efforts of different specialists and improved procedure for choosing experts for solving different problems, all this resulting in the improvement of the estimates they provide.

However, expert analysis is time consuming. It often takes a long time to prepare a program for expert analysis and to form the necessary team of specialists. In choosing a particular specialist for a particular expert analysis procedure, the reliability of their previous estimates should be taken into account.

There are several methods of using an expert team. One method – the individual method or method of coordinating estimates – is as follows. Each expert gives their own estimate independently of their colleagues, and then these estimates are merged into a single coordinated estimate. A second method – the collective method – is based on the joint work of a group of experts, resulting in a combined (collective) estimate for this group of experts. A third method – the Delphi method – involves the coordination of individual estimates in combination with the consecutive acquaintance of each expert with the opinion of their colleagues. At present, the individual method is the most widely used.

If we are considering the probability of a certain event or hypothesis, and an i-th expert evaluates this probability as P_i $(i = 1, 2, 3, \ldots, n)$, then, in this case, the simplest way to obtain the generalized (coordinated) estimate is to calculate the average probability P according to the following formula:

$$P = \frac{P_1 + P_2 + \cdots + P_n}{n} \tag{4.11}$$

where

$P_1, P_2, P_3, \ldots, P_n$ are estimates, obtained from an i-th expert;

n is the number of experts in the team.

We can also calculate the average-weighted value of the probability (P_n), attempting to take into account the "weight" of each expert. The latter is determined either on the basis of evaluating the expert's previous works (e.g. reliability), or judging by their position, qualification, erudition and, to a certain extent, intuition. Such an average-weighted estimate is calculated as:

$$P_n = \frac{R_1 P_1 + R_2 P_2 + \cdots + R_n P_n}{R_1 + R_2 + \cdots + R_n} \tag{4.12}$$

where

$R_1, R_2, \ldots, R_n$ denote the weight attributed to a certain expert;

$P_1, P_2, \ldots, P_n$ are probability estimates obtained from each of the experts involved.

This method for predicting human-induced changes in the states of marine ecosystems has a significant drawback: the opinion of the minority (which can sometimes be true) is neglected. For this reason it is very important to choose the right specialist for the expert analysis of the given problem.

As for *mathematical forecasting*, its main advantages are:

- objective character of the information obtained;
- high accuracy (provided the model is selected correctly);
- possibility of using computers.

Depending on the type of mathematical description of the object of forecasting and on the techniques of determining unknown model parameters, mathematical methods of forecasting can be categorized into extrapolation methods and methods of modeling development processes.

Extrapolation methods are based on studying qualitative features and quantitative parameters of the investigated object for a number of years (observation series), followed by extrapolating trends of change over the future period for which a forecast is required. In this case, it is important to take into account all the factors affecting the changes identified.

In mathematical terms, the extrapolation can be represented as follows. Let us assume that we know the value of a certain function $f(x)$ at the given points $x_0 < x_1 < \ldots < x_n$ lying within the interval (x_0, x_n). The procedure for determining the value of $f(x)$ at points lying outside the interval (x_0, x_n) is what we call "extrapolation". Extrapolation always gives us approximate values of $f(x)$, thus assuming a certain error, which can be calculated using special formulas developed for each individual extrapolation technique.

There are two types of extrapolation: spatial and temporal. Spatial extrapolation is the extrapolation of conclusions made about a certain part of a given object to the other parts or the whole of this object. Temporal extrapolation involves the extrapolation of conclusions made about the given object at present and in the past to the development of this object in the future. However, the problems of applying extrapolation procedures to objects of differing nature, and of determining the maximum possible "extrapolation intervals" (taking into account present and future trends in the development of the object) still remain unsolved.

The use of extrapolation methods for predicting human-induced changes in the state of marine ecosystems is feasible and valid. The ratio of the period for which observation data on the marine ecosystem were obtained to the possible extrapolation period is very important. For marine ecosystems, all relevant factors affecting the value of waste discharge should be taken into account, e.g.:

- improvement in water supply and water derivation technologies in industry and agriculture;
- improvement in waste water treatment;
- introduction of low-waste and wasteless technologies, and general improvement of all technological processes related, one way or another, to the use of marine natural resources.

It is necessary to develop a system of rigid constraints for the application of extrapolation methods in forecasting quantities of industrial, agricultural and domestic effluents, their composition and their impact on sea water quality.

The *normative method* (or *method of establishing standards*) is based on the prediction of results to be achieved in the future. A chain of events that will occur and measures to be adopted in connection with such events are investigated from the future to the present.

The use of the normative method implies the analysis of observation data, taking into account trends and potentials in development, and the existence of certain constraints. In technological forecasts, such constraints relate to the development of scientific and technological processes in the given branch of industry, and to the availability of financial and labor resources for practical measures aimed at the mitigation and/or elimination of consequences of marine environment contamination (or even the exclusion of environment pollution). In forecasts related to the protection of marine ecosystems against harmful anthropogenic impacts, such constraints will be the MPC and/or EPC values for different pollutants found in the marine environment.

In the section 4.2, we have already discussed some problems of the standardization of marine environment quality. The method of ecological standardization is a variant of the normative method. In using it, for example, for the purpose of substantiating ecological standards (norms), we must take into account that the response of different ecosystems to the same impact can differ greatly. Frequently, sanitary-hygienic standards set for human beings (e.g. an MPC for certain chemicals which would ensure adequate protection of the human organism against the harmful effects of such chemicals) can turn out to be unacceptable for certain types of marine animals and plants (although there is an erroneous view that MPC values for certain pollutants established for humans beings can automatically be adopted as MPCs for other living organisms, including marine biota.)

Traditionally, MPC values are established for a certain environment: atmospheric, open water, etc. As a result, in substantiating MPC values, the effects of chemical and biological accumulation of discharged pollutants, resulting from their passing from one medium to another (e.g. from water to air), are often underestimated or neglected. Transformation of chemical substances into more toxic forms and their accumulation within food chains are often neglected, too, in spite of the fact that the above-mentioned processes can be vitally important in revealing "critical" (most vulnerable) components of marine ecosystems. For example, the coefficient of accumulation of polychlorinated biphenyls, contained in many lubricants, pressure fluids and synthetic resins is 10^3–10^5 in fish, and 10^3–10^8 in aquatic mammals and waterfowl [88].

The current view of ecological standardization has been formed taking into consideration all possible routes of anthropogenic pollutants' migration into the environment, their chemical transformations, and the great number of possible ways they may penetrate into living organisms. Today, the normative method of forecasting is paid much attention all over the world.

In order to predict the amounts of pollutants that may be safely discharged into the marine environment by industrial enterprises, we must elaborate specific standards for these pollutants. Various multifactor mathematical models and relationships in which the permissible norms are described can be used to make a quantitative forecast using the normative method.

Each of the methods of forecasting (the limited space of this book does not allow us to describe all of them) has its own advantages and drawbacks. But, on the whole, modern forecasting methods can be regarded as a powerful new instrument of scientifically substantiated marine natural resources management and aquatic environment conservation. We recommend the following procedure for developing a forecast of human-induced changes in the state of a marine ecosystem:

(1) collection and analysis of observation data on the sanitary-hygienic, hydrochemical and hydrological conditions of the given sea basin area;

(2) study of the current industrial and agricultural waste-water discharge in the coastal area;

(3) mathematical and graphic processing of the data obtained;

(4) calculation of the balance of chemical substances discharged with waste waters;

(5) elaboration of the program and preparation of factual material for predicting possible changes in the marine environment in the given basin;

(6) development of extrapolation procedures for the basin, taking into account all of the above.

4.4. EVALUATION OF ECOLOGICAL CAPACITIES OF MARINE ECOSYSTEMS AND PARAMETERS OF THE MARINE ENVIRONMENT

The notion of "evaluation" reflects the relations between human society and the world around it. It is therefore necessary to give correct definitions of the object and subject of evaluation.

From the methodological point of view, the *object of evaluation* (estimation) is the marine ecosystem, while the *subject of estimation* is the economic complexes of various scales.

From the viewpoint of international law, marine ecosystems as objects of evaluation divide into ecosystems of the open ocean and ecosystems of the national waters of different countries. According to this classification, the subject of the estimation is the international and national regulatory bodies. Evaluation of marine ecosystems can be long-term (strategic) or current (operative) (Figure 4.2). Economic evaluation can be absolute or relative (comparative).

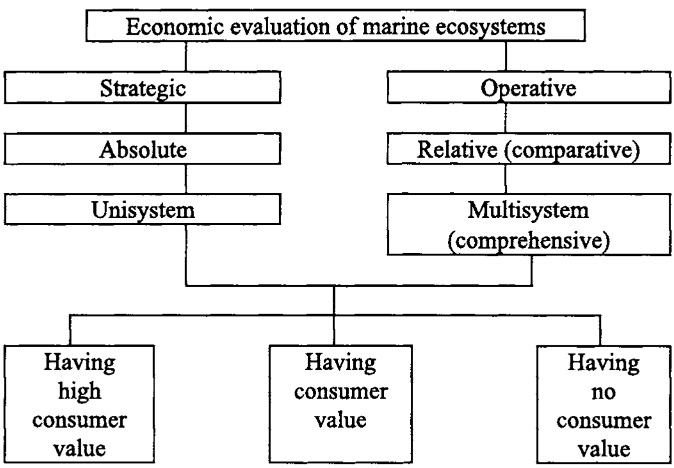

Figure 4.2. Scheme of Economic Evaluation of Marine Ecosystems.

According to the types of objects of evaluation, we can distinguish the economic evaluation of ecosystems of individual sea basins from the evaluation of a group of ecosystems in a particular region. Comparative evaluation of marine ecosystems of different water areas is always relative; absolute evaluation involves estimating the value of marine ecosystems, expressed in natural units, in monetary terms.

Thus, we suggest the following definition of the economic evaluation of marine ecosystems. *Economic evaluation of marine ecosystems* is the determination of their value in relative and absolute forms from the standpoint of a certain subject of management, and expressing the estimate thus obtained in monetary terms [126].

In order to carry out an economic evaluation of an individual marine ecosystem, we can use a generally adopted technique which involves estimating the economic potential of this ecosystem on the basis of the minimum cost of its resources management, as compared with the cost of managing another ecosystem adopted as a reference ecosystem.

With such an approach, the total unit (per 1 ton) costs of the finished product for the reference ecosystem (F) is compared with the same unit cost of the finished product for the ecosystem under consideration (H):

$$A = C_{\mathrm{F}} - C_{\mathrm{H}} \qquad (4.13)$$

where

A is the economic evaluation (EUR);

C_{F} is the specific unit cost of management of the resource potential of the reference marine ecosystem (EUR/ton);

C_{H} is the unit cost of management of the resource potential of the investigated marine ecosystem (EUR/ton).

It is clear from equation (4.13) that if $C_{\mathrm{H}} \le C_{\mathrm{F}}$, then the ecosystem under consideration is promising, and vice versa: if $C_{\mathrm{H}} > C_{\mathrm{F}}$, the development of the ecosystem will be inefficient. This conclusion is based on the fact that various ecosystems, functioning under different ecological conditions, are involved in economic activity, and the estimation based on equation (4.13) is of differential character. However, the absence of an unequivocal definition of the reference marine ecosystem and difficulties in expressing the consumer value of different ecosystems in monetary terms restrict the use of this technique. The location of the marine ecosystem in relation to markets where the products from it can be sold largely determines the economic value of this ecosystem.

For a particular calculation period, the specific unit cost of the finished product is determined for all the ecosystems whose economic development is projected for this period. The marine ecosystems are ranged according to the increase in comparable specific unit costs. The quantities of finished products obtained from the components of each marine ecosystem (as compared with the amounts of finished products from the reference ecosystem, for which any disturbance in its balanced state is excluded) are summed up as a progressive total, until the assigned demand value is achieved. Thus we identify the marine ecosystems that are resultant with respect to meeting the projected demands on their resources. In this case, specific unit costs will present the resulting costs of obtaining the projected amounts of products from processing resources of each ecosystem. In this case, the difference between the resulting and specific unit costs for the ecosystem will represent an economic evaluation of this ecosystem, which corresponds to the economic effects of its resources management.

The above technique is the basis for determining differential rent according to the resulting costs; thus we shall present the economic evaluation of the marine ecosystem using the differential rent criterion:

$$R_j = Z / H - C_j / H_j \tag{4.14}$$

where

j is the index of the marine ecosystem under consideration;

R_j is the rental economic evaluation of the marine ecosystem under consideration;

Z is the resulting costs;

C_j is specific unit costs for the analyzed ecosystem;

H and H_j are norms of raw material consumption per unit finished product of the reference marine ecosystem and the analyzed marine ecosystem, respectively.

Economic evaluation of marine ecosystems will present the effect of utilizing their components as raw materials in the production process exactly only if this effect is estimated with due account of assigned optimum demands for certain resources. Such assigned optimum demands depend on the food and consumer properties of the raw materials and determine, in turn, the quality of products obtained from these raw materials.

The cost of ecosystem restoration should be strictly differentiated between individual marine ecosystems. In order to make these costs comparable, it is necessary to elaborate comprehensive coefficients of the food and consumer value of the raw materials concerned.

The following calculation algorithm can be used to evaluate the useful biomass of the marine ecosystem (this biomass being regarded as the ecosystem's main resource):

(1) calculation of unit cost indices in wholesale (retail) prices, using data from statistical reports;

(2) calculation of cost indices of the total reserve of the marine ecosystem's useful biomass:

$$S_z = \sum_{i=1}^{i} S_i \cdot M_i \tag{4.15}$$

where

S_z is the cost of the ecosystem's useful biomass in wholesale (retail) prices (EUR);

S_i is the cost of the profit obtained from selling the products made from a particular component of the ecosystem's biomass per ton of this biomass (EUR/ton);

M_i is the total available reserve of the ecosystem's biomass (1000 tons).

It is also important to evaluate the self-restoration capacity of the marine ecosystem's plant and animal populations separately. The self-restoration capacity of the animal populations of the ecosystem under review can be determined as:

$$S'(t) = A \cdot Q \cdot k \cdot P \cdot r \cdot C \tag{4.16}$$

where

$S'(t)$ is the cost evaluation of the increase in a particular animal population of the analyzed ecosystem in wholesale (retail) prices, or the profit obtained from selling the finished products made from it, over the time period t (EUR);

A is the number of individuals in the useful stock (million);

Q is the average fecundity of a female over the time period t (1000 eggs);

k is the coefficient of the renewal capacity of the population of the marine ecosystem;

P is the average mass of a mature individual (kg);

r is the share of females in the population under review;

C is the cost of the product obtained from 1 ton of raw material in wholesale (retail) prices or the profit from selling the finished product obtained from this raw material (EUR).

The same equation (4.14) can be used to determine the self-restoration capacity of the given animal population of the analyzed ecosystem neglecting coefficient k.

The self-restoration capacity of the plant population of the ecosystem under consideration is determined as:

$$S''(t) = U \cdot N \cdot C \tag{4.17}$$

where

$S''(t)$ is the cost evaluation of the increase in the given plant population of the analyzed ecosystem in wholesale (retail) prices, or the profit obtained from selling the finished products made from it, over the time period t (EUR);

U is the total area of the sea bottom covered by the given plant population (ha);

N is the average mass of plants obtained from 1 ha of the sea bottom (covered by the given plant population) over the time period t (kg);

C is the cost of the product obtained from 1 ton of raw materials in wholesale (retail) prices, or the profit from selling the finished products obtained from this raw material (EUR).

Using equations (4.16) and (4.17), we can evaluate the "total" self-restoration capacity of the given ecosystem over the time interval t $[S(t)]$:

$$S(t) = \sum S'(t) + \sum S''(t) \tag{4.18}$$

where

$S'(t)$ is the cost value of the self-restoration capacity of all the animal populations of the ecosystem under review (EUR);

$S''(t)$ is the cost value of the self-restoration capacity of all the plant populations of the ecosystem under review (EUR).

More detailed calculations can help us evaluate the fodder organisms of the analyzed ecosystem (as recalculated for its fish). Economic evaluation of the fodder organisms resources of the given marine ecosystem over the time period t as recalculated for fish $[S_k(t)]$ can be represented as:

$$S_k(t) = \sum C_i \cdot M_{ki} \tag{4.19}$$

where

C_i is the profit from selling products obtained from certain fish species, as calculated per ton of fodder (EUR);

M_{ki} is the mass of fish of certain species resulting from utilizing this fodder over time period t (1000 tons).

Now let us ask ourselves: is it possible to make an economic evaluation of the balanced state of the marine ecosystem, as considered at the beginning of this chapter? The answer to this question is: yes, it is.

First we must outline the main approaches to such an evaluation. The value of the balanced state of any ecosystem is determined by its role in the generation of costs and profits. On the one hand, if a certain ecosystem is in a balanced state, it can partly utilize wastes from sea water, thus contributing to saving money that would otherwise have been spent on treating polluted effluents. On the other hand, the resistance of the marine ecosystem to contamination, and its ability to process and neutralize wastes, prevents damage (losses) that might be caused by deterioration in marine environment quality due to the effects of pollution.

It is expenses thus saved (or damage thus prevented), through the neutralization of harmful effects of pollutants thanks to the balanced state of the ecosystem, that must be regarded as the basis for economic evaluation of such a balanced state.

Ecological and social factors constituting requirements of marine environment quality can be represented in the following inequality:

$$Z \leq Z_u \tag{4.20}$$

where

Z is the amount of wastes neutralized by natural or artificial means;

Z_u is the maximum level of marine environment contamination permissible from environmental and socio-economic points of view.

Such limitation necessitates increased expenditure on nature conservation measures and, at the same time, helps us make economic evaluations of the balanced state of the marine ecosystem.

From the methodological point of view, economic evaluation of the marine ecosystem's balanced state is implemented within the framework of the differential approach, based on the concept of saved expenditure on marine environment protection against pollution and prevented damage which otherwise could have been caused to human society due to the deterioration of marine environment quality. In calculating the differential effect value, maximum possible expenditures on nature conservation measures for the given sea basin are considered as "closing" expenses. Note that such costs of nature conservation measures are determined as standard values of the maximum possible increase in the costs of waste water treatment and other nature conservation measures.

The maximum prevented damage (and not the maximum possible costs of nature conservation measures) is an adequate measure of this standard increase in "environmental" expenses. Let us remember that in nature, in the absence of human impact, the balanced state of marine ecosystems is maintained without any human efforts or expenses. But if the marine environment is subject to human impact – in this case, pollution – its balanced state will not be a self-maintained property, fully restorable by the ecosystem itself. In this case, its balanced state should be maintained artificially: it is important to prolong such a state over the whole period in which enterprises that discharge their waste into the sea basin under consideration will operate. The main difficulty is to determine the amounts of pollutants that can be safely discharged without modifying the properties of the ecosystem. This problem can be solved with the help of simulation modeling.

Thus, economic evaluation of a marine ecosystem's balanced state can be implemented taking account of the costs of both preventing pollution and preventing damage to the given marine ecosystem from pollutant discharge.

Marine ecosystems are dynamic. This means that the sum of all the living organisms of which it is composed changes constantly through interacting with the marine environment which also undergoes changes. Such interaction creates an energy flux of a certain structure, which creates substance turnover within the ecosystem and species diversity among its organisms. If the marine environment's conditions are relatively stable, the marine ecosystems remain stable, too. Changes in both the aquatic environment and marine ecosystems "inhabiting this environment" affect the self-restoration capacity of the latter.

On the one hand, marine ecosystems in the real world are energetically and structurally open, which allows substance and energy flow into them, thus making their existence possible. On the other hand, all marine ecosystems are connected to each other owing to interaction between their components, which are in a state of dynamic balance with respect to each other.

Any marine ecosystem is subject to the impact of numerous factors, both natural and human induced. Ecological factors can be divided into two groups: abiotic and biotic. *Abiotic factors* are phenomena and parameters of an inanimate nature: climate, illumination, chemical elements, and anthropogenic impacts. *Biotic factors* are interaction between different individuals and species: feeding, predation, competition, etc.

If the anthropogenic impact exceeds a certain level, it can disturb the ecological balance. In this connection, we should analyze one of the most important characteristics of the marine environment – its self-purification capacity. Knowing the quantitative parameters of this capacity, we can regulate pollutant discharge into the sea, taking into account the ability of the given marine ecosystem to neutralize the harmful effects of these pollutants.

The *self-purification capacity of the marine environment* is understood as a set of physical, chemical and biochemical processes that ensure the degradation and utilization of pollutants, resulting in the restoration of the natural (background) parameters of the marine environment, initially typical of its uncontaminated state. Note that, if utilization of pollutants is understood as their bioaccumulation, then this process cannot be regarded as self-purification. Accumulation of pollutants in bottom sediments or their export outside from the given water area are sometimes regarded as physical processes that result in the restoration of the background characteristics of the marine environment. This is incorrect.

From the biocenological point of view, the marine environment is considered as a water mass with dissolved substances, biota, bottom sediments and suspended solids; accumulation of pollutants in any of these components of the marine environment is inadmissible, because it will mean contamination of the marine environment. Therefore, such accumulation can never be regarded as a self-purification process.

Taking all of this into account, the self-purification capacity of the marine environment can be defined as the overall result of physicochemical and biological processes that ensure the elimination of pollutants from all the structural elements of the marine ecosystem – sea water, sea bottom, plants and animals, suspended matter.

In this interpretation, the self-purification capacity does not include removal of pollutants from the sea water as a result of:

- evaporation;
- bioaccumulation;
- transfer by sea currents;
- adsorption by seston and the bottom surface;
- washing-off from the bottom surface due to erosion;
- desorption by settled or suspended particles;
- sedimentation onto the bottom surface.

This is because all these process characterize pollutant migration in the marine ecosystem and are determined by natural abiotic factors. For example, evaporation of pollutants from the sea water surface depends on the wind velocity, water and air temperature, waves and physicochemical properties of the pollutants themselves.

It is important that the marine environment self-purification capacity is variable over a wide range in both time and space. The self-purification capacity of the marine environment arises mainly from the following processes:

- hydrodynamic transport;
- physical transformations;
- biochemical and chemical oxidation;
- biosedimentation;
- pollutants degradation by marine organisms.

However, the self-purification capacity tends to decrease under the effect of certain anthropogenic factors. Such decrease in the self-purification capacity is a negative phenomenon, from both ecological and economic points of view. We therefore consider the self-purification capacity (or potential) of the marine environment as a resource, and its degradation means the exhaustion of this very important type of resource, which entails additional (and in most cases appreciable) expenditure on waste treatment. If such expenses are not fully compensated for, a paradoxical situation may occur: the amount of untreated effluents discharged into the sea decreases, while the sea basin contamination becomes ever more intense. The reasons for a stable trend in self-purification's potential for degradation are mainly of an anthropogenic nature and are related to changes in the sea basin.

As was mentioned earlier, degradation of the marine environment's self-purification capacity is caused by human impact, leading to transformation of the natural conditions in the sea basin. The processes constituting this capacity are anthropogenically dependent. It is therefore only natural that their transformation under the effect of different types of human economic activity entails a decrease in the self-purification capacity of the marine environment.

Consequences of human-induced changes in the marine environment manifest themselves as:

- increase in sea water salinity due to withdrawal of river water for human use;
- increase in the concentration of readily oxidized organic substances in the sea;
- progressive dissolved oxygen deficit;
- changes in the pH and redox potential of the sea water;
- disturbance of the nutrients' balance, in particular, reduction in the phosphorus content of sea water.

In addition, sea water contamination has a direct negative effect on marine ecosystems (e.g. decrease in the biomass of animals, particularly filterers, such as benthos, zooplankton, etc.), which is described in detail in numerous scientific papers and books.

Under such conditions, the degradation of the marine environment's self-purification capacity becomes inevitable.

Taking all this into consideration, the elaboration of standards for discharge of effluents into the sea according to self-purification criteria is environmentally expedient. The self-purification capacity is determined through marine environment monitoring.

However, owing to the fact that the self-purification potential of the marine environment is a natural resource, in determining the economic efficiency of environment conservation measures, we should be guided by the criterion of restoring the self-purification capacity; this, in the long run, should be the objective of nature conservation measures.

If we regard the self-purification capacity of the marine environment as a natural resource, then we must consider the possibility of its development in the process of human economic activity, i.e. make an economic evaluation of self-purification potential as of any other natural resource. For example, according to our estimates, the value of the self-purification capacity of the Azov Sea, with regard to oil products and surfactants alone, is 3.5 billion EUR.

Assigning different ratios of the value of the maximum permissible discharge of certain pollutant to the self-purification capacity of the marine environment with regard to the same pollutant, we can plan water conservation activity in the sea basin and predict its results.

Analysis of the self-purification potential of marine environment as a natural resource, allows us to see that economic development, improvement of natural resources management, and scientific and technological processes transform our ideas about the natural potential that exists. Traditionally, the natural potential of economic development of any country (or region, or the whole world) consists of the natural resources of this country (or region, or the whole world).

The current concept of marine natural resources management necessitates a more comprehensive definition of the term "natural potential of economic development", which, in addition to the above, should include the notion of marine environment self-purification capacity.

From the point of view of methodology, one of the most important and difficult problems is the selection of criteria for economic evaluation of the self-purification capacity of the marine environment. To select such criteria, we suggest comparing the natural self-purification of sea water with technogenic treatment of waste water and pollutant neutralization. In this case, the unit expenses (Z_t), necessary for complete technogenic neutralization of a pollutant, equivalent to the water area self-purification capacity with regard to the same pollutant, is used as the criterion of economic evaluation:

$$Z_t = \sum_{j=1}^{n} (C_j + E_n \cdot K_j) \cdot P_j \qquad (4.21)$$

where

C_j is the normative cost price of the technogenic method of neutralization of a unit mass of the j-th pollutant (EUR/ton);

K_j is the unit capital expenses for technogenic neutralization of a unit mass of the j-th pollutant (EUR/ton);

E_n is the normative coefficient of economic efficiency of capital investments in the construction of a certain waste water treatment facility;

n is the amount of analyzed pollutants with regard to which the self-purification capacity of the given sea water area is estimated;

P_j is the mean annual value of the self-purification capacity (potential) of the given sea water area with regard to the j-th pollutant (tons/year).

Elaboration of a technique of economic evaluation of marine environment self-purification capacity suitable for practical calculations is necessary for economic evaluation of the ecological capacities of marine ecosystems in the marine environment under consideration. The *ecological capacity of the marine environment* is understood as the ability of its ecosystem to protect itself against any harmful impact due to a wide range of physical, chemical, biological and biochemical processes occurring within it. This ability is a protective function of marine ecosystems, which can be measured through its assimilation capacity. The *assimilation capacity* of a given marine ecosystem with regard to a particular pollutant (or a group of pollutants) is the maximum dynamic "storage" of such quantity of pollutants (calculated for the whole water area or a unit volume of the marine ecosystem) which can be accumulated, destroyed, transformed (chemically or biochemically) or exported from this ecosystem (due to sedimentation, diffusion or any other kind of transportation) per unit time without disturbance of the normal functioning of the ecosystem. The value of the assimilation capacity of the ecosystem depends on numerous natural and anthropogenic factors, such as water circulation and current water velocity, water temperature, density, salinity and transparency, structure and functioning of biota, and the concentration and chemical and physical properties of pollutants finding their way into the given ecosystem.

The concentration of pollutants (C_i) in the marine environment is a complex function, which can be represented as:

$$C_i(R, t_0) = F[q_R; V_R; \mu_{ij}; X_i; \lambda_i] \qquad (4.22)$$

where

q_R is the amount of toxic substances discharged into the sea by a certain point source of pollution;

V_R is the velocity of drifted pollutant transport;

μ_{ij} is the coefficient of physical transformation of the i-th pollutant into j-th one;

U_{ij} is the coefficient of chemical (biochemical) transformation of the i-th pollutant into the j-th one;

X_i is the coefficient characterizing the rate of pollutant accumulation by suspended organic substances;

λ_i is the coefficient characterizing the rate of microbial degradation of the i-th pollutant;

t_0 is the time required to determine the concentration of the i-th pollutant and compare it with the MPC for the same pollutant.

Although equation (4.22) reflects the dependence of pollutant concentrations in the marine environment on numerous factors, in practical calculations we should take into account only a limited amount of such factors, because they are interrelated and interdependent. Thus, processes of microbial and biochemical oxidation have a lot in common, but biological transformation of pollutants of plankton and benthic organisms is much less effective than their microbial oxidation. Even chemical transformations are less significant than microbiological ones, because chemical oxidation depends on the sea water temperature, which is known to be rather low.

Thus we can single out three basic processes determining the assimilation capacity (V_{ni}) of the given marine ecosystem:

- hydrodynamic processes (B);
- microbial oxidation of pollutants (D);
- biosedimentation (A).

Thus, the assimilation capacity can be presented as:

$$V_{ni} = B + D + A \qquad (4.23)$$

Evaluation of parameters of the marine environment and ecological capacities of marine ecosystems is one of the most important problems of marine ecologonomics. Without such evaluation, rational management of marine natural resources will be impossible. This evaluation will play a leading role in the elaboration of marine economic development strategy on a regional (and in the future, global) scale.

Concluding this chapter, we emphasize once again the importance of an ecologonomic approach to the evaluation of properties and parameters of marine ecosystems, to ensure better management of marine natural resources and increased efficiency of nature conservation measures – on both a regional and a global scale.

Chapter 5

PROSPECTS OF ECONOMIC DEVELOPMENT OF MARINE ECOSYSTEMS' NATURAL RESOURCES

5.1. IMPROVEMENT OF THE ECONOMIC MECHANISM OF MARINE NATURAL RESOURCES MANAGEMENT

The need for comprehensive scientifically substantiated solutions for all the economic and ecological problems of the present stage of marine economic development makes further improvement of the economic mechanism of marine natural resources management ever more necessary.

Improvement of the economic mechanism of marine natural resources management is understood as the development of control and regulation systems that would, on the one hand, increase the flexibility of the production sphere, and its ability to develop and implement new nature conservation projects, and, on the other hand, increase the efficiency of economic regulation levers. *Economic regulation levers* are defined as mechanisms of regulating commodity and monetary relationships, as analyzed for the marine economy in previous chapters of this book.

A conception of marine natural resources management in which any utilization of these resources was considered incompatible with protecting them was traditional in many countries [127]. A new conception of multipurpose management of marine natural resources, suggesting an absolutely new form of marine economic development, makes the older conception obsolete.

We should not oppose economic systems to ecological systems. Within the framework of the ecologonomic approach, marine resources management should become a complex multi-objective process that takes into account the depletability of these resources. Scientific and technological progress results in the intensification of marine natural resources production, especially of mineral resources production. The main restrictions on economic development (in addition to economic and technological ones) therefore relate to the existence of "environmental" limits on natural resources production and anthropogenic load on marine ecosystems involved in the production sphere. It should be noted that, at present, as a result of technological progress, the cost price of mineral resources production and recycling in the ocean is nearly the same as the cost of mineral resources production and recycling on the continents.

Back in the 1970s, the role of marine natural resources in the economic development of various countries and regions was recognized by many economists and political leaders [128], and since the beginning of the 1980s the objective of marine natural resources conversation has been pursued alongside the objective of resource production.

In 1986, the UN Commission on Natural Environment and Development suggested the principle of environmentally concerned development, which was adopted by the UN General Assembly. This principle envisages the use of technical facilities and technologies that will ensure environment conservation, while natural resources management should be implemented in such a way that these resources may be preserved for future generations [83].

We propose to analyze problems in the improvement of the economic mechanism of marine natural resources management as an example of the management of marine ecosystems resources.

Note that at present, both state-owned and private plants, factories and companies are engaged in the production of resources that tend to become exhausted, which will thus lead to a sharp decrease in the economic potential of marine ecosystems. Their natural renewal capacity has decreased to a level at which the natural self-protection capacity of the marine environment is insufficient to renew and conserve its natural resources. Ecological and economic problems relating to compensation for damage that has already been caused to marine ecosystems and to the prevention of future losses are therefore acquiring ever-greater prominence. Such a situation requires active engineering, technological, legal and administrative regulation of marine natural resources production, with the aim of increasing the bioproductivity of marine ecosystems, i.e. the organization of simple and expanded natural resources restoration.

Marine economic development should create favourable conditions for the establishment of reasonable demands on marine natural resources, as well as the renewal and conservation of the latter, assuming simultaneous preservation of the ability of the aquatic environment to neutralize harmful waste. Therefore, it is necessary to improve the economic mechanism of marine natural resources management in such a way as to preserve the balanced state of marine ecosystems involved in the production process. We are envisaging the creation of an ecologonomic mechanism of marine natural resources production, utilization, renewal and conservation [129].

In order to account for the environmental factor as fully as possible in marine economic development, it is expedient to analyze as many combinations of decisions on marine economic development as possible (including, if necessary, costs of preventing the depletion of marine ecosystems that are subject to human impact).

Any economic activity affecting marine ecosystems should be subject to ecological evaluation, i.e. determination of the degree of "environmental permissibility" of such activity. The procedure for assessing the environmental factor when determining the efficiency of marine economic measures should begin with analyzing projected economic measures according to the criterion of their environmental permissibility. As a result of such analysis, environmentally impermissible economic measures should be excluded from further consideration, and the remaining (environmentally permissible) ones should be ranged in accordance with their degree of ecological priority, which, in turn, must be taken into consideration in a process of evaluating the economic efficiency of the projected measures.

Estimation of the economic efficiency of marine natural resources management, including evaluation of the economic consequences of human impact and non-rational production of marine natural resources, is one of the most significant elements of the ecologonomic mechanism of marine natural resources management.

The economic efficiency of marine natural resources management is determined with the help of a simple inequality:

$$R_{C1} + P_{C1} + W_{C1} \leq R_{C2} + P_{C2} + W_{C2} \quad (5.1)$$

where

R_{C1} and R_{C2} denote the amounts of resources consumed in conditionally clean and contaminated marine environments, respectively;

P_{C1} and P_{C2} denote the amounts of product produced in conditionally clean and contaminated environments, respectively;

W_{C1} and W_{C2} denote the amounts of wastes formed in conventionally clean and contaminated marine environments, respectively;

C1 denotes conditionally clean marine environment;

C2 denotes contaminated marine environment.

At the same time, before launching any economic project, we must determine in principle the environmental permissibility of the given project, and it is only having done this that we can proceed to the evaluation of its economic efficiency. Environmental permissibility must be determined according to the following principles:

- indisputable priority of the preservation of the adaptation and self-restoration capacities of the ocean ecosystem;
- adherence to the terms and conditions of international conventions and agreements on the protection of marine natural resources and the aquatic environment;
- differentiated approach to the elaboration of ecologonomic strategy for marine natural resources management in sea basins with differing anthropogenic loads.

Let us assume that the production process occurring under the conditions of unchanged or slightly modified marine environment quality can be described by inequality (5.1). Irrespective of whether the marine environment is subject to changes or not, any economic project must undergo the procedure of determination of its environmental permissibility, and neither results of preliminary feasibility studies, nor sources of finance, nor any economic or political circumstances or factors may be permitted to affect the decision made on the environmental permissibility of impermissibility of the project.

What needs to be done to determine this environmental permissibility? First, based on the objective of the elaborated ecologonomic strategy of marine natural resources management, we must analyze international relations in the basin in question and international experience in developing and implementing similar projects, taking into account the criterion of permissible anthropogenic load on the given marine ecosystem. This means that we must specify the load value as the concentration of pollutants calculated in critical zones of the sea basin for each form of pollutant's discharge and their migration into the sea water area in question.

Based on the value of the permissible anthropogenic load adopted for this water area, the obtained load values are either corrected (reduced) or left unchanged. In accordance with the value of the permissible load thus obtained, marine economic projects that would lead to a load exceeding the permissible value will be recognized as inadmissible, whereas projects meeting the required limits will be subject to further analysis as environmentally permissible.

Since marine economic development should be aimed primarily at ensuring the renewal of natural resources of the ocean and the preservation of its ecosystem, improvement of the economic mechanism of marine natural resources management will require a full and accurate account of the expenses of marine natural resources reproduction included in the cost price of finished products obtained from the marine ecosystem's raw materials. Increased expenses caused by deterioration in the quality of the marine environment result in a higher cost price for the finished products, which, in turn, will lead to a decrease in profit.

Taking into account that both the cost price and the profit depend on the impact of the marine economy on the marine environment (and, therefore, on marine natural resources themselves), in a conventionally clean aquatic environment (inequality 5.1), marine economic development will be most effective, because a clean environment cannot have any adverse effect on marine natural resources management and the related production processes.

The ocean ecosystem is the source of marine natural resources. Any changes in marine ecosystems necessitate increased expenses for the improvement of resource production and procession technologies (E_t) and for marine environment purification against pollution (E_e) (if this is carried out). Economic damage (M) in this case is calculated as the sum of these expenses:

$$M = E_t + E_e \qquad (5.2)$$

However, equation (5.2) can be used only for an individual marine economic project. It cannot be applied to the marine ecosystems of the whole sea basin under review, to say nothing of the marine ecosystem of the whole World Ocean. This is because of the sluggishness of the marine environment: damage caused to it today by harmful anthropogenic impact becomes tangible and measurable only after 10–20 years or even longer. This again demonstrates the necessity of developing new technologies and of constant improvements in the economic regulation levers for marine natural resources management.

The process of marine economic development necessitates setting up international marine economic complexes, because, on the one hand, ecosystems of whole sea basins where several countries are located means all these countries become involved in economic development (thus any sea basin should be regarded as an international unit). On the other hand, marine economic activity involves the development of both aquatic and coastal branches of the national economy, so that we are faced with the problem of optimum combination of the interests of numerous marine countries, the development of cooperation between similar industries in the given sea basin under conditions of joint production, and management of natural resources from the same marine and coastal ecosystems.

Such cooperation permits the joining of efforts and the financial, labor and material resources of many countries for the purpose of developing and implementing certain economic and/or nature-conservation projects (e.g. joint construction of a water treatment plant that would maintain the required standard quality of the given ecosystem, or joint operation of an existing water treatment facility on the basis of shared use).

Optimum marine natural resources management should be aimed primarily at restoring the resources of marine ecosystems. If this requirement is neglected, this will have an adverse effect on both economic activity and the functioning of the ecosystems themselves. Thus, modernization of the principles and technologies of marine economic development should be environmentally substantiated.

The self-restoration and self-renewal capacity of marine ecosystems is the main factor in the development of the ocean's natural productive forces. Therefore, in the future, it will be necessary to ensure control over this factor.

Regulation of the marine economy should be reorientated from the solution of general economic problems connected with the production and utilization of marine natural resources, to the management of ecologonomic systems within individual sea basins (and in the future to the management of the ecologonomic system of the whole World Ocean). The main aim of such reorientation will be to provide favourable conditions for the renewal and protection of marine ecosystems' resources. In addition, improved economic regulation should meet the requirements of environmentally safe operation of industries and individual enterprises as an inalienable part of the renewal and restoration of resources. The ocean should be regarded as a unity and not just as a set of individual resources, relevant only for the production sphere.

Environmentally substantiated and environmentally orientated reorganization of the economic mechanisms of marine natural resources management is impossible without "ecologization" of the marine economy.

Marine natural resources management is regulated by means of setting legal standards for establishing labour, material and other relations between participants in marine economic activity, as well as by the introduction of administrative and economic incentive measures aimed at increasing responsibility and interest in implementing nature conservation measures, creating optimum prerequisites for the rational production, and use, processing and renewal of marine natural resources. Such regulation must ensure the preservation of adaptation and self-restoration capacity of marine ecosystems, and increase the efficiency of nature conservation measures.

The regulatory mechanism should establish the economic responsibility of those engaged in marine natural resources production and use, for the damage caused to the marine environment by their activities; compensation measures and penalties should adequately relate to the damage caused. In general, such mechanisms should:

- stimulate those engaged in marine natural resources management to prevent and/or reduce the damage caused to the marine environment;
- ensure the creation of monitoring systems in individual sea basins and in the whole World Ocean;
- help concentrate financial, material, labour, scientific and other resources necessary for the solution of marine environment conservation problems and for preserving the adaptation and self-restoration capacity of marine ecosystems involved in the production sphere – in the required place at the required time.

Under conditions of environmentally concerned development of the marine economy, regulation mechanisms should ensure the elimination of both internal (inter-regional and inter-branch) and international problems.

Marine natural resources are limited, which impairs the efficiency of the marine economy's functioning. Therefore, it is necessary to allocate a certain part of the profit to the purposes of marine natural resources renewal.

Preservation of the stability and balanced state of the marine ecosystem of a particular sea basin is the main criterion of the economic efficiency of marine natural resources management in that sea basin.

The main objective of improvement of the economic mechanism of marine natural resources management is intensification of resources reproduction. Intensive renewal differs from extensive renewal in that the latter implies only the utilization of the resources and capacities of marine ecosystems, whereas the former requires active human intervention in the process of natural resources renewal.

During the whole history of marine economic development, the extensive form of marine natural resources production and renewal has always prevailed over the intensive form. Until the time when the problem of resources depletion became acute, the need for economically and environmentally substantiated natural resources production and use was not recognized.

Thus, improvement of the economic mechanism of marine natural resources management is necessitated by:

- the depletability of these resources, which puts a natural limit on their extensive production;
- the existence of natural patterns in marine ecosystems which do not admit substances of anthropogenic origin to their natural cycles if they do not meet the respective ecological requirements.

The marine economy is facing problems of stabilizing the amounts of natural resources involved in production and the comprehensive multiobjective use of these resources which will permit the maintenance of the marine ecosystems' balanced state. Such stabilization of the quantities of natural resources involved in economic activity should become the basic principle of the functioning of the ocean ecologonomic system, which, in turn, would improve the economic mechanism ensuring environmentally safe management of marine natural resources.

Transition to the intensive form of marine natural resources renewal will require reduction in the amount of manual labour per unit useful effect. An increase in expenses related to environment conservation increases the value of so-called "past labour", which affects the efficiency of the marine economy's functioning today.

Ecological expenses in the production sphere can be defined as the sum of the necessary expenditure on protection, rational production and use, and renewal of marine natural resources. Such expenses can be reduced provided an economic mechanism is elaborated that could make the management of natural resources more efficient under conditions of preserving the self-renewal capacity of marine ecosystems.

Marine ecosystems should not be regarded merely as an external restriction on marine economic development; they should be considered as an integral part of the process of marine natural resources management, and an adequate economic mechanism should provide all the necessary conditions for both normal functioning of marine ecosystems and optimum marine natural resources management.

Life itself has demonstrated the advantages of developing and introducing low-waste or wasteless technologies, instead of attempting to improve and "ecologize" traditional technologies. Any technology, if it is really efficient, should envisage the recycling of waste. The introduction of closed cycles in natural resources production and processing can help preserve the balanced state of the ocean ecosystem.

The main and ultimate goal of improving the economic mechanism of marine natural resources management is to ensure the compatibility of marine economic operation with the normal functioning of marine ecosystems.

In our opinion, the main condition of improving the economic mechanism of marine natural resources management is increasing the efficiency of utilizing marine ecosystems' resources. Let us examine this in the case of the fishing industry.

The raw material basis of the fishing industry forms a component of the marine ecosystems' resources which can be utilized without disturbing the their natural renewal. The amount of such resources that is available at a given moment in time depends on the biological productivity of the marine ecosystems involved, the consumer value of raw materials and the conditions of the fishing areas. The aforementioned component of resources therefore refers not only to biological resources but to economic resources too.

Analysis of fish catch dynamics in the World Ocean, carried out over the period 1953–1996 [129], demonstrates that this dynamic Y_t can be described by a logarithmic curve equation:

$$Y_t = 1/a + b \cdot \ln t^{-kt} \tag{5.3}$$

where

a, b and k are coefficients characterizing the growth curve;

t is the length of the investigated or predicted dynamic series.

In order to predict possible fish catch values in individual sea basins, we suggest combining the use of the extrapolation method and the method of expert estimates. But first it is necessary to analyze the trends of fish catch increase in the basin under review over quite a long period of time and to estimate the probability of preserving these trends in the future.

The value of future fish catch can be predicted for individual sea basins using the following logarithmic curve equation:

$$Y_t = a + b \cdot \ln t \tag{5.4}$$

where

a and b are coefficients characterizing the growth curve;

t is the length of the investigated or predicted dynamic series.

Peculiarities of the marine ecosystems themselves and the great variety of requirements made for the possible withdrawal of a certain component of resources from these ecosystems necessitate identifying two stages in carrying out an economic evaluation:

(1) selection of a fish catch area with optimum quantitative and qualitative parameters;

(2) estimation of the comparative efficiency of fish catch development in this region and expression of the estimate obtained in monetary terms.

In the first stage of calculations, we must identify three groups of parameters of economic evaluation:

- parameters characterizing the amount of available marine ecosystem resources and trends in their variation;
- parameters characterizing natural conditions that affect the forms of fishing organization and its technological equipment;
- parameters describing environmental conditions that affect the quality of resources produced.

The first group of parameters includes biotic and abiotic factors that have a considerable impact on the formation of the component of marine ecosystem resources that can be withdrawn. A forecast should then be made for all the components of the aforementioned part of the ecosystems' resources, which will allow us to:

- estimate the value of production reserves, establishing the potential for producing each type of marine ecosystems resource in the areas defined as production areas, over the forecast period;
- determine seasonal variations in the formation of productive concentrations of individual populations, which should correspond to the maximum efficiency of fishing for the forecast period;
- calculate the amount of populations that are regarded as production items and estimate the possibility of entraining new populations in the production sphere, in order to characterize the productive reliability of selected fishing areas.

Management of marine ecosystems' resources should be based on wise fishing. Allowing private companies, interested only in obtaining maximum profit from fishing, access to production areas leads to disastrous extermination of fish and other resources of marine ecosystems. For this reason strict state control over the amount of resources produced and the kind of production technologies used should be exercised so as to ensure stable fish stocks in the future.

Our task is to introduce parameters characterizing the efficiency of management and protection of economically feasible types of resources into the economic comparison of costs and effects of marine natural resources production. The introduction of such parameters is necessary to ensure optimum (from the viewpoint of the long-term economic interests of marine countries) regimes of production, renewal and protection of various types of marine ecosystems' resources.

These efficiency parameters involve economic evaluation of unit resources, and estimation of the consumer value of fishing areas in terms of their productivity. After making such evaluations, on the basis of their results we can determine the value of the damage caused to marine ecosystems by violation of the regime of marine natural resources production and by the decrease in bioproductivity resulting from aquatic environment contamination.

In forecasting the production of marine natural resources, we must first predict the value of fish catch whose withdrawal is permissible. *The permissible withdrawal value* is that part of marine ecosystem resources which can be used by the fishing industry without disturbing the natural self-restoration capacity of the marine ecosystems involved.

The forecast of the permissible withdrawal value should be made based on the patterns of marine ecosystem behaviour in the past and at present, and on their projected future behaviour. Due to the peculiarities of the object of forecasting (in this case a particular marine ecosystem), the accuracy of the forecast is largely determined by the duration of the forecast period: the longer the forecast period, the less accurate of the forecast. We can ensure high accuracy in the forecast of the permissible withdrawal value only for the time interval during which the catching of fish (whose population we know at present) will begin. Usually, the duration of such a period is about 5 years, depending on the lifespan of the given fish species. The forecast of the permissible withdrawal value is a result of expert estimation, based on research and experimental data and on historical data on the quantities of particular resources and general trends in their variation. The results of such a forecast can be presented both for individual production areas and for the species composition of the marine ecosystems involved in the given type of production.

The forecast of the permissible withdrawal value for individual production items and fishing areas allows us to determine the possible species composition of the total catch.

Provided the required input data are available, the species composition of the future catch should be determined on the basis of an estimate of the comparative economic efficiency of particular production items for each analyzed area separately. The average profit obtained per ton of catch can be used as a criterion for such estimation.

If the information required for comparative economic evaluation is not available, the species composition of the total catch can be determined using the expert method, based on available forecasts and taking into account a whole range of factors, such as the food value of the fish, seasonal variations in catch values, the maximum diurnal value of fish catch, demand for the corresponding fish products, etc.

There is another way of forecasting the total catch value, whereby the initial estimate of the catch for the "closing" years of the forecast period is carried out by extrapolating over time the fish catch values in the past. However, such a method can be helpful only in making a very approximate forecast, subject to correction in the future.

In order to select the best variant of marine ecosystem resources management, several versions of fish catch forecast must be considered.

The possibility of multivariant forecasts of fish catch is created by the availability of different ways (from the viewpoint of efficiency) of withdrawing the required component of resources. Such multivariance of forecasts can cover the values of fish catch, its structure and production areas, the ratio of mariculture development to fishing, and some other factors.

The fish catch forecast can be presented as a univariant forecast only when, based on information about the resources of the given marine ecosystem, various development scenarios have already been elaborated and analyzed, and the optimum one has been selected.

In order to carry out economic evaluation of marine ecosystems' resources, it is expedient to analyze the scenario of maximum withdrawal of all production items in accordance with the value of maximum permitted fish catch, and the minimum scenario, in which with maximum economic effect the market becomes saturated in the given type of products obtained from the marine ecosystem in question.

In this case, it is necessary to ensure that the economic mechanism of marine natural resources management envisages adherence to the requirements of environmentally safe production, which must be regarded as an indispensable element of the process of resources renewal, the ocean being treated as a single whole, and not merely as the sum of many individual resources possessing consumer value.

5.2. Protection and Renewal of Marine Ecosystems' Resources

The varied and complicated character of measures on production, processing, use, renewal and conservation of marine natural resources achieved at present and projected for the future requires completely new approaches to the planning and organization of such measures. As for the resources of marine ecosystems, recent efforts and funding have been focused on the development of technologies and technical facilities for their production. But now the moment has come when we are faced by overproduction and depletion of these resources, both in the quality of their composition and in their consumer value. For example, the catch of valuable marine fish (such as salmon, cod, rockfish, etc.) has diminished in the total catch, whereas the share of so-called "garbage fish", having little nutritional value, has increased. As a result, the scope for fishing (as a typical representative of a producing branch of the marine economy) has decreased to a level at which the natural self-protection and self-restoration capacities of marine ecosystems can no longer ensure the adequate renewal of their resources [130].

Any human influence on the marine environment occurs as a chain of inter-related processes. Sometimes, their consequences can manifest themselves only after a certain (rather long) period of time, because of the ocean's inertia. Any disturbance (impulse, heat flux, pollution, biological transformation, etc.) causes a reaction in the marine environment which depends on qualitative and quantitative parameters of both the environment itself and the disturbing impact in question. This problem was discussed in Chapter 3, where we analyzed the ecological and economic consequences of marine environment contamination.

Marine natural resources are limited, and this hampers industrial development; thus, natural resources renewal is now becoming a socio-economic factor. This means that the process of resources renewal requires human efforts (by this we do not mean to say that natural resources and their production and renewal have now become independent of the natural environment).

The notion of *renewal of marine ecosystem resources* should include, in addition to natural processes, the participation of people, promoting not only the formation of certain components of these ecosystems, but also their restoration and conservation [131]. Therefore, when determining the efficiency of the production and use of particular natural resources, we must take into account the cost of their renewal and protection.

Economic efficiency is always determined according to a certain selected criterion. In choosing such a criterion for determining the economic efficiency of marine ecosystem resources production and use, we should be guided by the nature of their renewal [132]. According to the type of renewal, we can distinguish three groups of marine ecosystems:

(1) ecosystems with prevailing artificial renewal of their components;

(2) ecosystems with natural renewal prevailing over artificial renewal;

(3) ecosystems for which both natural and artificial processes of renewal are equally important.

However, artificial renewal of marine ecosystem resources cannot yet compete with their natural renewal in the formation and replenishment of reserves of resources.

There are two types of resources renewal – simple, and expanded. *Simple renewal* is understood as restoration processes that ensure the availability of the same amounts of resources that were available before they began to withdrawn. It is maintained by a system of measures, among which rational withdrawal of resources and environment conservation are the most important ones. In contrast, *expanded reproduction* restores increased amounts of the given resources owing to optimization of their production and renewal and more efficient environmental conservation activity. Note that the effects of expanded resources renewal may be achieved under the conditions of simple renewal: the amounts of restored resources remain equal to those of the withdrawn resources, but the resources are utilized more efficiently due to their enhanced processing, achieved by the application of up-to-date processing technologies, allowing us to obtain greater amounts of finished products from the same amounts of raw materials.

The consumer value of marine ecosystem resources is no less important for the estimation of the economic efficiency of their production, utilization and renewal. In order to estimate the quality of marine ecosystem resources as raw materials for manufacturing the required finished products, we suggest using special consumer value coefficients, which reflect the consumer (in the case of fishing, nutritional) value of the analyzed resources in comparison with a certain type of resource selected as a reference. Such coefficients may be:

- general indices characterizing the value of the given type of resources from the viewpoint of its possible use as raw materials for producing a whole range of finished products;

- indices characterizing the value of the given type of resources for production of one or several types of finished products.

In addition, the estimation of profits and losses resulting from the utilization of the resources under review or from disturbance of the process of their renewal, and expression of the resulting estimates in monetary terms are very important for estimating the efficiency of marine ecosystem resources production and renewal. This is because they can provide economic stimulation of rational management of marine natural resources, both for individual enterprises and branches of the marine economy directly engaged in marine ecosystem resources production and renewal, and also for other branches of the marine economy whose operation affects (directly or indirectly) the quantity and quality of marine ecosystem resources.

To illustrate this, let us analyze the procedure for calculating the economic efficiency of setting up a farm for artificial breeding of salmon in a certain region. The economic efficiency in question, $E_{(s)}$, can be represented as the difference between the cost of the finished products (artificially produced salmon, its meat and caviar), on the one hand, and certain additional costs related to their artificial production and sale, on the other hand:

$$E_{(s)} = P - (C_r + C_{ps}) + A \tag{5.5}$$

where

P is the cost of artificial finished products obtained at the farm, i.e. salmon meat and caviar (EUR);

C_r is the cost of the salmon's artificial renewal (EUR);

C_{ps} is the cost of processing the artificially produced salmon (EUR);

A is additional expenses (EUR).

The evaluation of profits and losses in monetary terms is applicable for:

- calculation of cost indices for marine ecosystem resources as an element of the national wealth of any country;
- substantiation of various projects of research, exploration, production, conservation and renewal of the resources of any marine ecosystem;
- calculation of the value of damage caused by the diminishing size and deteriorating quality of marine ecosystem resources resulting either from marine environment contamination or from the negative effects of resources production technology;

- establishment of payment for the use of marine ecosystem resources and penalties for damage caused to the marine environment.

On the basis of this, we can conclude that economic evaluation of the efficiency of marine ecosystem resources is directly connected with the economic value of these resources, i.e. their quantity and quality.

The *economic value of marine ecosystem resources* can be defined as the long-term economic effect of their production and utilization, depending on:

- the quantity of the resources in question that can be increased by means of artificial renewal;
- techniques of resource production in the given sea basin (for fishing, this includes fish-catching facilities, type of vessels, etc.);
- details of resource processing (most marine ecosystem components can be used as raw materials for a great number of finished products).

Within the framework of the ecologonomic approach we have suggested, in selecting criteria for the economic evaluation of marine ecosystem resources, that we must be guided not only by the necessity of meeting the market demand for certain products obtained from these resources, but also by the requirement of maintaining the optimum level of their renewal.

The cost of renewal of a particular type of resource in a given region should become the basis for calculating the efficiency of marine ecosystem resources management in this region. Such costs should include the cost of resources renewal, and their processing and transportation (the latter being taken into account for both raw materials and finished products obtained from them).

One of the main parameters of the economic efficiency of renewal of marine ecosystem resources is the index of water area economic value (U^t_j), which reflects the integral effect of management of all resources of the marine ecosystem in the given water area:

$$U^t_j = \sum Y^t_i \cdot Q^t_i \tag{5.6}$$

where

t is time period involved;

Y^t_i is the specific rental index;

Q^t_i is amount of resources of the i-th type available for the time period t.

The magnitude of penalties for aquatic environment contamination should be established according to the type of pollutants discharged, their concentration and migration over the given sea water area, and the value of the damage caused by the contamination. In general, the value of the total economic damage, resulting from the decrease in bioproductivity of the given marine ecosystem caused by marine environment contamination, should include losses incurred due to the decrease in the quantity of resources which could be produced during the period in which the pollution takes effect, but were not produced because of this pollution, and due to the decrease in the nutritional and consumer value of the resources in question (e.g. for fishing, including losses of juvenile fish and fish fodder).

The main difficulties in the practical calculation of damage arise from the absence of adequate information on marine environment contamination (types of pollutants, time of pollutants discharge, their concentration, migration and transformation properties, quantity of resources affected by them, etc.). At the same time, current approaches to the evaluation of damage which are based on the prediction of expected losses, estimated in accordance with the present cost of products obtained from marine ecosystem components, are not sufficiently substantiated and reliable, because only the costs of environment conservation measures are taken into account, but their results are neglected.

The analysis of concrete scenarios of marine ecosystem resources production, use and renewal can help us obtain the required set of economic estimates and specify related damage indices on the basis of these estimates. All this will require elaboration of numerous scenarios of management of marine ecosystems resources, based on available technological, economic, geographical and other information. The forecast of unit costs of primary resources production for different scenarios of their processing and ultimate utilization should include a forecast of the availability and amount of resources in question, the method of their production and processing, the use of their finished products and the market demand in these. Such economic analysis and forecasts can be improved by the use of various statistical methods and simulation and optimization models.

Let us now consider some problems of the artificial renewal of salmon on the Pacific coast (Far East Region) of Russia. At present, the amount of salmon available in this region is determined mainly by the efficiency of its natural renewal, which, in turn, depends on:

- the size of the parent shoals (spawners) on the spawning grounds;
- the effects of biotic and abiotic factors that determine the natural death rate of progeny;
- specific features of fish populations and their individual elements which determine the potential maximum adaptation to the given area;
- the "catch-out load" on the given sea water area, which affects the size and structure of parent fish shoals and, therefore, the reproduction of the fish species under consideration.

All these factors are inter-related and can manifest themselves independently or in different combinations, depending on the situation, which necessitates a special approach to the analysis of every large shoal (or a group of shoals) of salmon.

For example, humpback (*Oncorhynchus gorbuscha*), found on the north-eastern and western coasts of the Kamchatka Peninsula, is a short-period species with a simple shoal structure. The number of individual humpback fishes in the shoal and the number of shoals themselves are therefore subject to considerable variation, caused by abrupt changes in ambient conditions. This can be explained by the fact that unfavourable conditions for the reproduction of one generation, caused by a shortage of spawners, can lead to depletion of fish resources for several cycles. Another reason for a decrease in the amount of humpback is over-fishing (or excessive catch-out load).

At present it has been proved that humpback of odd and even generations (fish generations born in odd years are regarded as "odd generations", and fish generations born in even years are regarded as "even generations") are individual isolated populations, divergent to such an extent that they demonstrate pronounced genetic differences. There are also ecological differences between these two generations: under normal conditions, even generations are usually less productive.

This difference makes excessive fish production in one generation dangerous, because the restoration of fish numbers could take place only under especially favourable reproduction conditions, or a marked decrease in fish catch, in order to bring about normal filling of spawning grounds by spawners.

In terms of its production value, chum (*Oncorhynchus keta*) takes second place (after humpback) among Far Eastern salmon species. Compared to the humpback population, the structure of the chum population is more complicated and its reproduction rate is much lower. In contrast, the chum population is subject to the impact of harmful ambient factors to a lesser extent then humpback, and under conditions of optimum production the numbers of chum can be maintained at quite a high level for a long period of time.

The restoration of industrially available fish stock takes 10–12 years, where no measures for its artificial restoration are carried out and commercial fishing is restricted by the open-sea and near-shore zones.

Kokanee, or redfish (*Oncorhynchus nerka*), is produced in Russia only in the Kamchatka Peninsula, where two big shoals of this fish are found, which are the basis for their commercial catch-out, along with several smaller shoals, which have lost their commercial value at present because of over-fishing.

Coho, or silver salmon (*Oncorhynchus kisutch*), can be caught in the sea within one production season at the age of 1–2 years before they reach maturity. This is explained by the short period this fish spends in the sea. Under normal conditions of migration to spawning grounds (freshwater bodies in the Russian Far East), the catch of silver salmon can be increased 3–4 fold.

The most valuable salmon fish is chinook (*Oncorhynchus tschawytscha*). Its other names are "king" and "saw-keivey". Like redfish, it is fished for only in Kamchatka. Owing to the early time of spawning and its large size, chinook is not caught during its migration to spawning grounds. Prepubertal chinook, in which form this fish is caught in the sea, do not form shoals, and that is why they are taken as "additional catch" in the process of fishing for other types of salmon.

During the last few decades, some growth in the numbers of chinook has been observed due to favourable reproduction conditions and the "optimization" of biocenotic relations caused by the reduction in the number of other species of salmon.

In addition to the means of artificial renewal, the size of the salmon fish shoals in the Russian Far East could be increased by:

- regulation of fish catch-out on the basis of strict control over the state and productivity of salmon;
- application of severe economic and legal sanctions against poachers.

A practical realization of these measures alone could help double the annual salmon fish production in Russia.

Although artificial breeding of salmon is one of the most promising directions in increasing the Far Eastern salmon shoals, in our opinion normalization of their natural renewal, not requiring massive financial and material resources for the necessary nature conservation measures, would also promote an increase in salmon numbers (provided adequate spawning grounds are available).

Usually, for salmon populations that are not subject to excessive catch-out load, the average rate of natural reproduction is maintained within the limits of a pair of spawners being replaced by two offspring. Inevitable fluctuations in the value of such a limit are explained by natural patterns in the dynamics of the numbers of the fish species in question.

One of the most important parameters in the fishing industry (especially in the branch dealing with the artificial breeding of fish) is the *replacement index*, defined as the ratio of the number of pubertal fishes which come to the spawning ground where they were born, to the total number of hatchlings which hatched from the spawn (under natural conditions) or were let out into natural water bodies (lakes and rivers) from artificial fattening tanks or ponds (under conditions of artificial breeding). Sometimes the replacement index values may be expressed as a percentage. The replacement index, calculated on the basis of values of absolute fecundity, is 0.02 for chinook, 0.07 for chum, redfish and silver salmon, and 0.13 for humpback.

If the catch-out ratio is maintained at the level of 50%, and if the fish population is stable, the average value of the replacement index for salmon can be twice as high. In contrast, abrupt changes in the number of fish, caused by ambient factors affecting the conditions of their reproduction and survival, can entail considerable variation in the value of the replacement index.

For example, in the natural reproduction of humpback, the replacement index can vary from 0.01 during a period of significant depletion of fish reserves to 0.12 for a period of increase in the number of fish. The amplitude of fluctuations in the replacement index is somewhat less for fish with a complicated shoal structure; however, in certain generations of even these fish, variations in the index can reach several per cent.

Low values of replacement index can be explained by high mortality of fish roe (spawn) in the process of natural reproduction. Losses incurred due to fish roe death, together with pre-incubation losses, add up to 20–100% of the average fecundity value. The mortality of baby fishes is also high: it can reach 99% of the total number of fish that emerge from the spawn.

All these facts testify in favour of artificial breeding of salmon, aiming, primarily, at stabilization and increase in the value of the replacement index, mainly through decrease in the natural mortality of fish roe.

There are two ways of organizing a salmon farm: extensive and intensive. The *extensive* method ensures a decrease in fish spawn mortality, and most of the Russian Far Eastern fish farms operate on this basis. Under natural conditions, the mortality of salmon fish roe varies within a very wide range (Table 5.1).

Table 5.1. Fish roe losses in the process of natural reproduction of Far Eastern salmon shoals

Salmon species	Average fecundity (numbers of eggs)	Eggs losses during spawning (% of fecundity value)	Eggs mortality in nests (% of total amount of spawn)	Number of eggs that survive	Loss ratio
Humpback	1500	40	20	720	2.1
Redfish	3000	30	25	1570	1.9
Chum	3500	50	15	1490	2.3
Silver salmon	4000	50	20	1600	2.5
Chinook	9000	80	3	1750	5.1

Reprinted from: A.V. Souvorov, *Economic Efficiency of Hydrobionts Reproduction.* Proc. Conf., Petropavlovsk-Kamchatski: Publ. of the Regional Committee for the Young Communist League, 1986, p. 53.

Artificial reproduction of salmon ensures a decrease in spawn mortality of 2–3%. As a result, due to an increase in fish roe mortality alone, artificial breeding of salmon in the Russian Far East could be several times more efficient than natural reproduction. However, in practice, such low values of spawn mortality on the Pacific Coast of Russia have not yet been achieved, and, as a rule, the efficiency of artificial salmon breeding does not greatly exceed that of natural reproduction. This is explained primarily by the conditions of artificial fish egg incubation differing greatly from those of natural fish egg incubation. As a result, artificially produced hatchlings turn out to be less resistant to harmful environmental effects than naturally produced ones, and high rates of fish roe survival are later neutralized by the increased mortality of baby fish.

Therefore, the development of biotechnology for artificial salmon reproduction should be aimed at making the conditions of artificial spawn incubation and hatchling growth as close as possible to the natural conditions of spawn incubation and hatchling growth.

The *intensive* method of salmon breeding involved organized farms. Juvenile salmon are grown under artificial conditions until they become viable, and special food is provided for them. Most fish farms in Japan, Canada and the USA operate on this intensive basis. As a result, the mortality of hatchlings decreases by 30–50%, while their vitality and their resistance to harmful environmental conditions increase.

Russia has little experience yet in intensive artificial breeding of salmon, which is explained by the shortage and high cost of the special artificial food for baby fishes. But the international practice of intensive artificial breeding of salmon demonstrates its high efficiency.

The value of the replacement index is found to be largely dependent on the increase in the weight of juveniles let out into natural water bodies from artificial fattening tanks or ponds. Table 5.2 presents comparative data of the efficiency of silver salmon reproduction, calculated on the basis of field observation data collected during one of the expeditions organized by the Ecological Center 'FENIX' of Moscow State University.

In Japan, intensive artificial breeding of chum ensures that the replacement index value exceeds 0.02. This means that about 60 pubertal individuals born from one pair of chum spawners come from the sea to the spawning grounds. This is ten times more than under conditions of natural chum reproduction.

In the USA and Canada, the replacement index value for chinook under conditions of artificial reproduction (in which juvenile fish reach a weight of 2.5–3 g) is about 0.25, which is five times more than under conditions of natural spawning. Note that, if the weight increase of hatchlings is 8–10 g, the replacement index value becomes as high as 0.8, which is 16 times higher than the replacement index value under natural conditions.

Table 5.2. Parameters reflecting the efficiency of artificial reproduction of silver salmon, as recalculated for 1 million pubertal individuals.

Weight increase in juveniles let out into natural water bodies (g)	Replacement index (%)	Amount of fish eggs (1000 pieces)	Number of spawners (1000 pairs per ton of fish)	Commercial fish production (tons)
0.3	0.002	500	660	1980
3.0	0.02	200	280	2580
10.0	0.12	40	40	2940

Reprinted from: *Field Trips held by the Staff of Ecological Center 'FENIX'* Moscow State University. Scientific Report Preprint, 1997, p. 87.

In the USA, from a group of silver salmon juveniles with a weight increase of 15–18 g, a remarkable value of replacement index equal to 0.36 was obtained. All this evidence indisputably testifies to the promise of intensive methods of salmon farm organization, and to the potential for significant increase in the quantity of salmon on the Pacific Coast of Russia, provided that artificial salmon breeding is introduced on a commercial scale, comparable to the scale of the salmon catch.

Another method of artificially increasing the size of Far Eastern salmon shoals is to increase the spawning and fattening areas. This would require strict control of all the existing spawning grounds and implementation of environment conservation measures, in order to make previously contaminated rivers and lakes in the coastal zone suitable for fish spawning and fattening. Construction of artificial fish passages, allowing fish to come to their spawning grounds, might also contribute to an increase in the quantities of valuable salmon species.

One of the most serious problems requiring urgent solution is the silting and overgrowing of spawning grounds, resulting from mineral and organic fertilizers applied in the river basins in which the spawning grounds are located.

Restoration of natural spawning grounds (which have been damaged for various reasons) by means of fish egg placement on prepared sites does not require very large capital expenditure and would greatly accelerate the process of restoration of salmon reserves exhausted by over-fishing.

The mortality of fish roe placed in specially prepared artificial nests using the technique elaborated at our Ecological Center does not exceed the fish roe mortality under natural conditions. In addition, hatchlings from such nests prove to be much more viable than those coming from fish farms. This method is also used in other countries. For example, in Japan it has ensured the restoration of the redfish shoal in the Gandzibepu River. In Canada, the use of this method has allowed a significant increase in the number of salmon in the Fraser River.

Another promising way of increasing the efficiency of artificial salmon renewal is the application of fertilizers in water bodies used for the spawning and fattening of fish. The experience of Canadian scientists who applied phosphate and nitrate fertilizers, enriched in microelements, to the Big Central Lake for 5 years testifies to the efficiency of this method, which ensured a 20-fold increase in the number of kokanee in this lake (from 50,000 to 1 million individuals).

Among all the water areas and adjoining land areas of the Russian Far East, the Kamchatka Peninsula is the best place for the artificial renewal of salmon. Judging by its natural conditions, Kamchatka seems to be specially created for this purpose. On the geological timescale it was recently an island, and its rivers are not yet inhabited by fresh-water fish, which grow slowly but consume much food. Owing to this fact, the whole natural food base of the internal water bodies of this peninsula is consumed by juvenile salmon, and therefore valuable species of salmon such as redfish, silver salmon and chinook, which cannot be found in other regions of the Russian Far East, live here.

Kamchatka is famous for the variety of its natural zones. The eastern and northern (continental) parts of the peninsula are mainly mountainous; here vertical zonality can easily be traced in the climate, soils and vegetation cover. Depressions with flat, frequently swampy floors are located among the mountain ranges. By contrast, the western part of the peninsula consists of plains and lowlands.

The south-western part of Kamchatka is a heavily fragmented upland of volcanic origin, where almost all of the peninsula's active volcanoes are concentrated. Thermal hot springs can also be found here.

Such favourable physicogeographical conditions for salmon reproduction can be found neither in other regions of the Russian Far East, nor in any other part of Eurasia. The absence of permafrost, the great water accumulation capacity of the soils, the high values of the river runoff modulus in both winter and summer (which exceed those of rivers in the Russian European Territory by 5–10 times), and considerable ground-water runoff are all conditions which make the Kamchatka Peninsula unique.

Ground water, passing through porous layers of volcanic rocks, widespread on the peninsula, ensure constant washing of the soils in the places where salmon spawn. Thick snow cover and bushes protect fish roe from freezing in winter.

Thus we can see that Kamchatka provides all the necessary conditions for large-scale operation of salmon farms, in order to achieve artificial renewal of salmon shoals. This can be illustrated by the experience of natural resources management in Alaska, which, in terms of many natural parameters, can be considered as an American analog of Kamchatka. Initially, Alaska was valued only for its gold, but in the 1950s it became clear that the price of all the gold produced in Alaska was less than the value of the furs sold from this region. The value of salmon sold from Alaska also exceeded that of gold (note that the gold reserves are now depleted, whereas salmon can still be produced and hence still make a profit.)

The problem of reproduction and appreciable increase in the number of Far-Eastern salmon can be solved under conditions of:

- optimization of the natural conditions of salmon reproduction;
- scientifically substantiated fish catch regulation;
- large-scale artificial reproduction of salmon;
- increase in the productivity of fish farms.

At present, in the Kamchatka Peninsula, the share of artificially reproduced salmon is only 2% of the total production of salmon in the Far East. This is a negligible contribution.

Let us now say a few words about the specifics of the artificial reproduction of salmon. First, salmon juvenile fish are easily injured and must be kept safe under artificial conditions until they become old enough not to get injured during their long journey to the spawning grounds.

Second, salmon roe must be incubated for a long period of time (4–6 months) at a temperature of 2–5°C. Spawners must be kept in specially equipped places in the narrowest parts of the rivers. Fish eggs are obtained and artificially fertilized in special shops; after swelling the fish eggs are transported to the pond.

Humpback juveniles are let into the rivers after they can find food for themselves, and are then no longer fed artificially. In contrast, chum juveniles are fed artificially in special tanks for hatchlings or (using the latest technology) in special fattening ponds. Artificial reproduction in Kamchatka can ensure a 7–10-fold increase in the survival rate of chum and humpback, compared with their natural spawning in rivers.

Using geothermal springs, it is possible to provide food for fish on the basis of local plant resources. This is very important, because the development of special food formulae for chum baby fish, and the use of "live food" play a very important role in the preparation of juveniles for their future independent life in river estuaries.

As was mentioned earlier, one promising way for increasing the numbers of salmon in the Russian Far East is the application of fertilizers such as ammonium phosphate and ammonium nitrate (in low concentrations) in lakes. These fertilizers increase the rate of primary production of substances in water bodies, thus providing more food for zooplankton, which, in turn, serves as fodder for salmon during their stay in the lakes and so would bring about increased survival rates for hatchlings. For example, the application of mineral fertilizers into the Kurilskoe and Kronotskoe lakes could increase the number of kokanee in these lakes by up to a total of 8–10 million pieces and commercial production of this valuable species of salmon up to a total of 25,000–30,000 tons.

Table 5.3. presents the estimated total demand in capital investment for the development of the salmon branch of the fish industry in the Kamchatka Peninsula.

Note that fish farms' operation will be efficient only after they have created their own shoals of salmon fishes. Depending on the species of salmon, the period for achieving the full projected capacity of such a farm can be 3–12 years after the first group of hatchlings produced at the farm were let into natural rivers and lakes. Table 5.4. presents the values of expected economic results of the development of the salmon branch of the fish industry in the Kamchatka Peninsula.

Provided the required number of salmon fish farms are constructed in the Kamchatka Peninsula, and provided their effective operation is ensured, salmon production in this region could be increased two-fold and even more (by artificial fish reproduction). By the end of the forecast period (the year 2020), about 162.46 million EUR of profit could be obtained from this sphere of the marine economy.

An additional economic effect from artificial salmon reproduction could be achieved through the development of chemistry and pharmacology: production of biologically active substances (e.g. trypsase, ubiquinone, etc.) from non-food wastes obtained from the disposal of salmon bodies.

As was mentioned earlier, in addition to artificial reproduction, even distribution of catch-out load over individual populations of fish in accordance with their quantity and the norms of permissible withdrawal can also become the basis for their rational management. It is not by chance that, during the period of marine fish-catch intensification, many populations of salmon were practically destroyed and could no longer participate in the reproduction process.

Table 5.3. Demand in capital investments for the development of the salmon branch of the fish industry in the Kamchatka Peninsula (million EUR)

	Years				
	1997–2000	2000–2005	2005–2010	2010–2015	2015–2020
Total amount of required capital investment including investment for:	69.9	81.1	81.1	123.4	44.0
objects of industrial destination, comprising:	47.0	55.0	55.0	115.0	38.0
(a) fish farms	41.6	53.9	53.9	113.5	37.5
(b) fishery fleet	0.9	1.1	1.1	2.5	0.5
objects of non-production destination, comprising:	22.6	25.1	25.1	20.4	6.0
(a) scientific, experimental and trial objects	11.4	4.7	5.0	4.8	1.0
(b) housing objects	11.2	11.4	15.1	15.6	5.0

Our calculations show that avoidance of non-productive losses, caused by unwise fish catching, could allow a 1.5-fold increase in salmon production in the Kamchatka Peninsula.

Our example, showing the potential for rational production and reproduction of salmon on the Pacific Coast of Russia, serves as a good illustration of the economic efficiency and profit that can be achieved by any country that concerns itself with the wise management of its marine resources and their renewal and conservation.

Finally, we would like to emphasize the main advantages of artificial renewal of marine ecosystem resources:

First, it becomes possible to meet the market demand for a given product not only through the natural self-restoration of resources used for their production, but also through artificial renewal of the resources under consideration.

Second, the quality of the resources produced is improved owing to the selection and formation of the required properties of the marine environment, which has a direct impact on the quality both of resources themselves and of the final products obtained from processing them.

And third, purposeful formation of certain resources and their environment simplifies their production, which leads to a decrease in the cost of the finished products.

Table 5.4. Expected economic effect of the development of the salmon branch of the fish industry in the Kamchatka Peninsula

	Unit of Measure	Years				
		2000	2005	2010	2015	2020
Total fish catch	1000 tons	0.15	17.44	48.2	75.04	134.23
Commercial production	million EUR	0.41	47.8	132.16	205.77	368.1
Expenditure	Million EUR	0.22	26.7	74.1	114.95	205.64
Profit	Million EUR	0.19	21.1	58.06	90.82	162.46
Total additional expenditures, including:	Million EUR	1.1	13.37	20.65	30.16	33.71
(a) operation and maintenance cost of fish farms	Million EUR	0.6	11.97	18.62	29.26	33.35
(b) research and development expenses	Million EUR	0.5	1.4	2.03	0.9	0.36
Economic effect	Million EUR	–0.91	7.73	37.41	60.66	128.75

5.3. Program of Conservation and Renewal of Marine Ecosystem Resources in Russia

Elaboration of a national program of conservation and renewal of marine ecosystem resources in Russia is necessary for two reasons:

- the constantly increasing level of marine contamination;
- the inability of traditional ways to organize the marine economy to increase production of marine ecosystem resources.

According to the forecasts of experts, by the beginning of the twenty-first century, the demand for marine ecosystem resources will exceed the permissible level of their withdrawal by 30–40% [81].

In this book, we have already discussed the damage that is caused to the marine economy (in particular, the fishing industry) by aquatic environment contamination. This damage manifests itself in complete or partial destruction of certain plant and/or animal populations and deterioration of the quality of marine ecosystem resources produced.

Elaboration of a national program of conservation and renewal of marine ecosystem natural resources should include the determination of the damage caused to them by marine environment contamination, which is very important for the fishing industry and other branches of the marine economy. This concerns not only direct consumers of marine natural resources but also other enterprises located in the coastal zone whose operations affect (directly or indirectly) marine environment conditions.

Correct calculation and forecasting of damage are also important for the elaboration and implementation of scientifically substantiated measures for prevention of marine environment contamination and elimination of its harmful consequences.

The main problems to be taken into account when developing a national program are as follows:

- determination of the level of contamination in each basin and its effect on the ecosystems of the basin;
- determination of natural damage and its evaluation in monetary terms;
- determination of the compensation costs of preventing or eliminating the damage;
- determination of the economic efficiency of these costs.

Forecasting of human-induced changes in marine ecosystems is an important component of the program. Such forecasts should be based not only on input data obtained from constant observations of the state of individual populations, but also on observation data for the state of the marine environment itself.

In order to elucidate patterns and trends in human-induced changes in the marine environment, data collected over the past 10–15 years should be arranged in series and then analyzed.

This method – the observation series method – allows us to identify patterns in natural processes occurring in marine ecosystems, and patterns of pollutants migration and transformation, their effect on the marine environment and response of marine ecosystems to such aquatic environment contamination.

When making a forecast, it is important to analyze variations in the intensity of different sources of pollution and other sources of disturbance in order to predict factors affecting the marine environment, including, especially, human economic activity.

Such forecasting is a stage-by-stage process.The *first stage* of predicting changes in the state of marine ecosystems that are subject to anthropogenic impact consists of calculations based on the assumption that in the future the economic development of the region under consideration will remain at its present level.

In the *second stage* of forecasting we analyze the available plans for intensification of economic activity in the region and carry out ecological expert examination of all the suggested projects. If we come to the conclusion that the implementation of these projects will entail increased marine environment contamination, then we must include in each project measures aimed to decrease such contamination or to neutralize the effects of intensified pollution if the latter turns out to be inevitable.

In order to work out the so-called "zero variant" of the project, we assume that there will be no sources of pollution in the given basin from a certain moment in time.

The forecasting of human-induced changes in the state of marine ecosystems allows for a better assessment of all geophysical, geochemical and biophysical processes related to pollutant migration and transformation in the ocean, special attention being paid to possible increases in the toxicity of the pollutants discharged.

The *third stage* is the prediction of possible changes in the marine ecosystems under the effects of pollutants that have already found their way into the marine environment, and of other factors existing at the time the forecast is made.

The *fourth stage* is the prediction of changes in marine ecosystems caused by newly discharged pollutants and other newly emerging factors.

We consider the ecosystem of the World Ocean to be a single unit. Therefore, changes occurring in it under the impact of human economic activity can affect its various components over a long period of time (especially when we consider genetic consequences), even if this impact is later reduced or completely eliminated.

Analysis of predicted states of marine ecosystems allows us to select priorities for economic incentives and sanctions aimed at eliminating the negative effects of pollution. This analysis, in addition to a set of measures aimed at decreasing existing negative effects, enables the elaboration of preventive measures against negative effects that are not yet apparent.

Thus, forecasting of changes in marine ecosystems is a very important part of controlling marine environment quality, and, therefore, an indispensable stage in elaborating a national program of conservation and renewal of marine natural resources, which, in turn, should aim to maintain the ecological balance of the marine environment.

Since the anthropogenic load on marine ecosystems is considerable, because of the intensive withdrawal of resources from the ecosystems, another way to maintain the ecological balance in the marine environment (in addition to marine environment protection against contamination and other damaging effects), worthy of attention, is artificial renewal of animal and plant populations that are depleted due to excessive production. This approach can only be used under conditions of an obligatory decrease of production "take-out load" in the sea basin under review. One of the advantages of artificial renewal of marine ecosystem resources is a considerable decrease in the cost of exploration and production for these resources.

According to expert estimates, in the seas adjoining Russian territory the water areas suitable for artificial renewal of marine ecosystems resources add up to no less than 30,000 km^2.

We use an ecologonomic approach in elaborating a program of conservation and renewal of marine ecosystem resources in Russia. Our interpretation of the term "renewal of marine ecosystems resources" therefore differs from the traditional understanding of mariculture, especially as intensive development of the latter can itself cause considerable damage to marine ecosystems. Thus, one of the main aims of the program is to ensure optimum use of the self-restoration capacity of marine ecosystems.

Within the framework of the ecologonomic approach, any projects aimed at intensifying the use, expansion and improvement of the structure of coastal waters' biological potential on the basis of expanded renewal of valuable species of hydrobionts, or transplantation of the most valuable objects of cultivation to other places, and projects, aimed at artificially increasing the fertility of coastal waters should be submitted to a process of careful ecological expert examination.

The effect of scientific and technological progress on the expansion of areas suitable for artificial renewal of marine ecosystem resources cannot be neglected either. Development and practical application of industrial methods of cultivation, selection and adaptation, and genetic engineering techniques allow hydrobionts to be modified, making cultivation possible in a greater range of environments.

In the first stage of elaborating a national program of conservation and renewal of marine ecosystem resources, based on the results of preliminary analysis of the self-restoration capacity of ecosystems located in the waters within Russia's 200-mile economic zone, we must determine the possible scope of increase in the resources of these ecosystems which could be achieved by the implementation of measures for their artificial reproduction (Table 5.5).

Table 5.5. Possible total increases per decade in marine ecosystem resources in Russian coastal waters (in thousand tons)

Year	Fish	Invertebrates	Algae
2000	23.3	11.2	10.0
2010	54.6	26.8	22.0
2020	120	54.0	56.0

Taking into account the market demand for marine products and progress in the comprehensive raw material processing (including an increased processing degree of raw materials), by the year 2010 about 37,000 tons of food products, 29,800 tons of products for agriculture, 24,700 tons of products for medicine and pharmaceutics, and 11,500 tons of products for other branches of the national economy would be produced through the implementation of measures for artificial renewal of marine ecosystem resources. By the year 2010, the increment in marketable products will amount to 174.6 million EUR, and by the year 2020 to 373.6 million EUR.

The value of returns on assets will amount to 0.3 EUR/EUR in 2000, 0.5 EUR/EUR in 2010, and 1 EUR/EUR in 2020, the profitability being 10.5, 17.3 and 30%, respectively. Labour efficiency will improve from 15,800 EUR/person in 2000 to 26,800 EUR/person in 2010 and 49,600 EUR/person in 2020. The demand in capital investments will be 317.5 million EUR over the period 2000–2010, and 664.6 million EUR over the period 2010–2020 (Table 5.6).

The most important condition for obtaining these amounts of resources from marine ecosystems through the implementation of measures for their artificial renewal is the effective utilization of the scientific, technological and design experience of leading organizations and institutes, and the stimulation of business activity in this sphere of the national economy.

According to our preliminary estimates, the costs of research and development work for the period 2000–2010 will be 43.6 million EUR, and for the period 2010–2020 they will be 59.5 million EUR (Table 5.7).

Normative parameters of the national program under consideration include certain regulatory requirements for in-depth processing of raw materials (Table 5.8).

Table 5.6. Dynamics of the structure of capital investments in conservation and renewal of marine ecosystem resources (million EUR)

Elements of the structure	Period		
	1997–2000	2000–2010	2010–2020
Production sphere	90.4	193.4	404.8
Construction work in coastal areas	38.9	82.8	173.4
Construction of items of non-production character	19.4	41.3	86.4
Construction of items for environment conservation purposes	29.1	62.0	129.9
Total	177.8	379.5	794.5

Table 5.7. Costs of research and development work (million EUR)

	Period		
	1997–2000	2000–2010	2010–2020
Total R&D costs	24.1	43.6	59.5

Table 5.8. Degree of raw material processing in industry

	Year			
	1990	2000	2010	2020
In-depth processing ratio	72%	78%	95%	99%

As mentioned earlier, returns on assets, cost-effectiveness (profitability) and labour efficiency are also referred to the main regulatory requirements of the program.

Table 5.9. Regulatory fund allocation requirements for projected enterprises engaged in artificial renewal of marine ecosystem resources

Parameter	Unit	Year		
		2000	2010	2020
Return on assets	EUR/EUR	0.3	0.5	1.0
Profitability	%	10.5	17.3	30.0
Labour efficiency	EUR/person	15 800	27 200	49 600

Values specified in Table 5.9 must be regarded as the economic prerequisites for purposeful economic activity aimed at artificial renewal of marine ecosystem resources within the framework of the law on business enterprises.

Meeting the regulatory funds allocation requirements will allow enterprises engaged in artificial renewal of the natural resources of marine ecosystems to operate on the basis of self-repayment and self-financing, without any tax privileges being introduced for them.

However, meeting these requirements of the program within the established forecast period (2000–2020) will be possible only if during 1997–2000 all the necessary research and development is carried out. For example, in the salmon and sturgeon branches of fishing industry, it will be necessary to develop new food formulae and feeding technology, introduce closed-loop water supply systems, etc.

The Far East is the best region of Russia for artificial renewal of marine ecosystem resources, because of the high fertility of the seas adjoining the Pacific Ocean, and the vast shelf areas suitable for setting up fish farms and other enterprises engaged in artificial renewal of the natural resources of marine ecosystems (Table 5.10).

The natural conditions of Russian coastal waters, unlike in many other countries, impose severe restrictions on setting up of fish farms, because in Russia there are practically no bays that are properly protected against sea waves and winds, and that remain unfrozen throughout the year. In many regions there are no tidal currents to ensure the export of wastes from fish farms nor to enrich the water with oxygen; the low water temperature (0–2.8°C) in most of the bays is also a restriction. Moreover, the social infrastructure in the coastal areas suitable for setting up special farms for artificial renewal of marine ecosystem resources is underdeveloped.

Nevertheless, the scientific and technological potential of Russia allows us to hope for successful scientifically substantiated development of such farms on the basis of elaboration and implementation of a purpose-oriented national program of conservation and renewal of marine ecosystem resources.

Needless to say, any program, especially a development project which must necessarily envisage environmental measures that will require financing, cannot be a success (or even launched) without finances. Financing is a critical issue in this kind of business.

The financial situation in Russia is grave. We shall not dwell here upon the shortage of money, the inappropriate distribution of State funds, and difficulties in sponsoring development programs and environmental projects, particularly in far-away regions such as the Far Eastern Region. Instead we will say a few words about general principles of financing environmental measures – which were initially elaborated for industrially developed countries, but, in our opinion, might be applicable for Russia in the near future, provided it pursues a course of reform of the national economy with the aim of introducing market relations.

Table 5.10. Dimensions and fertility of Far Eastern sea water areas suitable for setting up special farms for artificial renewal of marine ecosystem resources

Sea	Sea water areas suitable for setting up special enterprises (1000 km^2)	Average fertility (tons/ha)		
		Fish	Invertebrates	Algae
Sea of Japan	1	150	150	60
Sea of Okhotsk	4	255	150	55
Bering Sea	15	60	150	40

Financing of environmental measures in both the public and private sectors will depend on:

(1) type of financing instruments used;

(2) determination of the government to raise sufficient funds;

(3) ability of the economy to generate funds: the higher its economic growth, the greater this ability will be.

The finance strategy for environmental purposes might be based on the following main sources:

- governmental financing, consisting of revenue from central government and local government, charges raised on publicly provided services, other environmentally related revenue and "eco-taxes";
- financing by industry of its own pollution costs, and by public/private companies of projects of environmental infrastructure;
- international financing, particularly from international lending institutions.

Governmental financing. The government should aim to reduce future financing requirements to a minimum by putting maximum emphasis on preventive policies in industrial investment, energy production and use, transport policy and resource production, processing, use, renewal and conservation. For each sector, a specific strategy needs to be elaborated with the aim of preventing increased pollution and waste of resources. A start has already been made in some areas. The use of natural gas in some urban areas has significantly reduced pollution, and the associated cost is relatively low and largely borne by the individual householders who benefit from cleaner air. Similarly, strategies to develop public transport in major metropolitan areas will produce environmental benefits. Such an overall strategy must include the enforcement of pollution control investment and the introduction of low-waste and wasteless production technologies in new industrial plants. This strategy will also shift the burden of financing to the private sector.

The backlog in publicly provided environmental services, such as water and sewerage systems and solid waste collection, treatment and disposal, is considerable and the need is especially urgent since public health is endangered and serious damage has been caused to water resources and coastal waters. The main source of financing for these services should be user charges, preferably calculated on the basis of the long-term full social cost of providing such services. These costs should also take into account the cost of resource depletion, the environmental costs associated with the provision of the services, and the high inflation rate. Although the government should aim for the full recovery of capital and running costs, there will be circumstances where for reasons of equity they cannot be fully recouped and will have to be financed from taxes. In a number of cases, developers can be forced to provide sewerage and water services as a condition of their obtaining a development permit. Such a policy would relieve the government of the burden of financing these developments and could be applied to other sectors of economy. The management aspect of financing publicly provided services must be a joint effort by central and local governments.

The government could raise additional funds for environment by imposing development taxes on land in cases where building permits provide considerable profits. These taxes could be tied to performance in fulfilling environmental requirements and could be largely raised by local government. Additional public funds could be made available by transferring subsidies presently granted to developers in tourism, industry and commerce to the providers of these public services. These funds could be used for creating environmental infrastructure with little or no loss to the economy.

Penalties and fees for non-compliance with environmental regulatory standards should be more strictly enforced than at present and the funds thus obtained should go in full to the municipalities that impose them. These funds should be spent on public treatment installations.

Product charges could be imposed on certain polluting products, both to reduce their use and to generate funds for waste disposal and treatment. Similarly, deposit refund schemes and performance bonds would produce revenues in cases where compliance with environmental regulations is not feasible, such as disposal of hazardous waste or surface mining.

Financing of pollution control by industry. A significant proportion of industry in Russia is state owned. Some of it is old, inefficient and highly polluting. A large proportion of this industry is located in densely populated areas; its pollution therefore affects many people. Some of these enterprises will have to be reconstructed and subsidized; however, many plants will have to be closed soon for both economic and environmental reasons, instead of being reconstructed. Finance for pollution control subsidies could come from effluent charges imposed on all plants in a particular river basin.

Although subsidizing the development of new technology itself is often necessary, no subsidy should be provided for investment in new plants or for pollution prevention and control in either the public or the private sector. Environmental regulations must be enforced, and this should lead both domestic and foreign investors to use the latest low-polluting technologies, which are usually the most profitable ones.

Differentiated taxation of polluting fuels would also provide additional revenues and at the same time discourage the use of the most polluting fuels.

Large investment projects could be jointly financed through public/private partnerships. The private sector would provide the investment funds and running costs in return for collecting revenues for a limited period, after which the infrastructure would be returned to public ownership. Alternatives are privatization of certain public services with strict governmental control over price and quality provided. These might include water, sewerage, waste disposal and conservation services.

International financing. For quite a long period of time, almost all sectors of the Russian economy will depend on foreign investment. Investment for environmental purposes could also be financed from foreign sources. Criteria of "economic viability" from environmental investment can be met in many cases, provided the appropriate investment analysis is carried out over a sufficiently long period.

Conditions for financing. Various conditions have to be complied with if the funding mechanisms suggested above are to operate successfully:

(1) large capital expenses, such as for sewerage and water treatment, will have to be financed through credit, and it should be the responsibility of the central and local government to raise these funds from either internal or international sources. This credit will then be recouped through proper pricing and charging. Although Russia will be facing considerable budgetary difficulties for some time in the future, this should not be used as an excuse to delay such investments.

(2) funds raised through economic instruments in the field of pollution control or conservation and also from certain taxes, such as fuel taxes, could either be marked and paid into a special environmental fund, or retained by the municipalities raising them in order to finance their environmental services.

(3) strict governmental and public control over funds allocated for environmental conservation purposes.

(4) introduction of the "polluter pays" principle where possible.

5.4. Elaboration of Marine Natural Resources Management Strategy at the Regional Level

Before analyzing principles and criteria of elaborating marine natural resources management strategy at the regional level, let us discuss briefly some general problems of coastal zone management. From an environmental perspective, coastal zone management needs to be evaluated according to the following criteria:

- integration of policy objectives and achievements;
- administrative structures for implementing policy;
- availability of legal instruments;
- financial mechanisms to achieve objectives;
- implementation of coherent environmental policy in coastal areas.

For the reasons cited earlier – contradictory policy objectives and legislation, weak administrative integration, lack of relevant legislation, and environmentally harmful financing arrangements – environmental policy is implemented in a haphazard and limited manner. Pollution control regulations for industrial enterprises are not rigorously enforced, and fines have proven to be ineffective. Insufficient protection of natural areas outside specially protected zones and the absence of municipal waste water treatment and industrial pollution control have resulted in severely contaminated waters in many coastal areas of Russia.

In general, there is no coherent environmental policy: the implementation of existing regulation is either weak or non-existent, environmental impact assessments are rare, and there is only nascent recognition of the need to prevent environment degradation.

The results of this evaluation of the major causes of environmental degradation of Russian coastal areas (as well as coastal areas in the other countries of the CIS), including coastal waters and marine resources, provide a framework for recommendations on improved management. The assessment of the quality of the coastal areas indicates that, although many areas of the coast are still untouched, the high rate of deterioration in some areas, rapid spread of pollution, and other effects require immediate corrective action. Unless some action is taken in the near future, damage to coastal resources, including economic damage, will accelerate and could, for example, result in the total and irreversible ecological collapse of bay areas and the extinction of fish species in some coastal regions.

Authorities need to recognize and seize opportunities for action which require minimum additional finance and whose effects will be immediate and long-lasting. This needs to start with a concentration of efforts to integrate policy formulation and implementation. There are therefore five broad areas for policy recommendation:

- reconciliation of policy objectives in coastal regions with special regard for sustainable development of coastal resources;

- integration of the administrative arrangements for coastal management and appropriate definition of areas from both regional and national points of view;
- creation of a legal framework through the drafting of new coastal laws and their reconciliation with existing laws;
- adherence to existing environmental laws and regulations through cooperation between municipalities and governors of the coastal provinces;
- creation of financing mechanisms for coastal protection through a combination of central government funds and regional funds generated by local taxes, fines, penalties, user charges and tourism development fees, and the discontinuation of subsidies for polluting activities.

General principles of environmental policy implementation in coastal regions. Implementation of environmental measures should be administered by the government and the municipalities, using all the existing provisions and mechanisms in various policy areas, as well as specific instruments of implementation necessary for the coastal zone management. Such implementation should comprise the following components:

- long-term indicative plans for major coastal regions, including detailed land-use plans for both the municipalities and areas outside their administration;
- plans for the development of coastal waters (marine ecosystem resources, aquaculture and reclamation);
- overall development of the coastal areas according to the directions of local authorities;
- adherence to the existing laws on nature conservation and human health protection, both in coastal land areas and in coastal waters, through the use of regulatory and economic instruments – the latter to include: specific actions to restore damaged ecosystems (such as estuaries and bays), critical habitats, and the living conditions of endangered species;
- special financing measures for the coastal regions;
- specific measures complying with international obligations in coastal zones, laying particular emphasis on coastal waters.

Long-term development plans for major coastal regions should be prepared through collaboration by the appropriate ministries, including the national environmental authorities. These plans should identify the areas where developments are likely to be concentrated over the next 20–25 years. Such indicative plans would assist local authorities in the preparation of land-use plans, and those responsible for environmental infrastructure, with particular attention to sewerage.

Land-use planning at the municipal level is a crucial element in defining both the population density and industrial activity along the coast and, therefore, the likely load on the environment. Consequently, land-use planning should take into account environmental considerations, including pollution loads, the aesthetic (landscape) aspect and the provision of green areas. Present land-use planning practices need to be improved. In a context where land rights are often disputed, there is an urgent need for the clarification of ownership and for the establishment of a land register. In order to prevent coastal erosion, the removal of sand and shingle from the shoreline needs to be controlled on the basis of coastal resource inventories and an understanding of the sediment transport processes along the particular coastline.

While speaking about the overall development of coastal management areas, we want to emphasize once again that each project should be subject to careful expert analysis, special attention being paid to environmental issues and rational economic development. This process should comply with established regional norms and these criteria should be developed and applied to the entire range of land, air and water resources both on land and in coastal waters to ensure sustainable management of coastal-water and marine resources.

Adherence to nature conservation laws and concern for human health protection issues is very important for successful coastal management. Although this is of general concern to Russia as a whole, it is a particularly urgent issue in its coastal areas.

Compliance with international obligations in pursuing an environmentally minded strategy of coastal economic development at the regional level should be part of the overall implementation of the strategy. This should involve:

- compliance with the various international agreements already signed by Russia on pollution of coastal waters and the sea;
- special measures for highly endangered areas, such as the Black Sea.

Let us repeat that economic development of oceans and seas is closely connected with the land and especially its coastal zone. The links between the areas in question are becoming tighter, gradually acquiring a long-term character. This makes the formation of special zones that include a part of both the land and the water surface areas a prerequisite. Being an inalienable part of such industrial zones, ocean water areas exercise considerable effect on the formation of these zones' economic and territorial structure. Thus, a relatively independent zone of combined aquatic and terrestrial-industrial character is formed, with its own specialized functions. We call this zone *aquaterritory*.

Regarding the coastal area as a natural–economic contact zone including the coastal area and continental shelf, we can state that the formation of an aquaterritory is largely determined by the principle of "a limited compact zone". This zone serves as a basis for the functioning of auxiliary and servicing industries. The size of the identified adjoining water area depends on the development projects for production, use, conservation and renewal of particular types of marine natural resources. As a rule, this area does not exceed that of the 200-mile economic zone under the jurisdiction of each maritime state.

The development of an aquaterritory is determined by several factors: administrative, spatial, economic and environmental. The aquaterritory's natural resources should be managed according to an ecologonomic approach, involving the elaboration of a specific development strategy. The latter assumes the use of a system of parameters and techniques enabling the estimation of the level of resources production, use, renewal and conservation, and the elucidation of the main development trends and regulatory methods.

The sum of the objects, ecologonomic relations and methods of their investigation which characterize the aquaterritory's development, laying special emphasis on its natural resources, is called the *research area.*

The diversity of material, economic, political, social and other phenomena and their interrelationships which characterize the aquaterritory necessitate the use of a wide range of methods of investigation which are suitable for application in this research sphere. Research methods may include:

- investigation of analogous phenomena and their ecological–economic relations;
- means of ensuring the invention and application of new methods of studying the given aquaterritory.

Let us call the selected means of research the "research instrument". The main difficulty in selecting the research instrument is the variable character of the problems to be solved and the diversity of research methods (mathematical, software, methodological, etc.) used to solve them. It is therefore essential that the selected research instrument is versatile, i.e. it must:

- reflect the research process itself in studying the strategy of aquaterritory natural resources management;
- promote the expansion of the sphere of scientific activity – studying new features of the aquaterritory and comprehensive analysis of the links and relations described earlier;
- serve as an experimental basis for analysis of current approaches to the investigation of the aquaterritory's natural resources;
- ensure improvement of the quality of scientific research by supplying verified scientific means that will help us to trace and then implement in practice the development trends in aquaterritories.

When the means of research is chosen, the researcher can proceed to elaborate the management strategy for aquaterritorial natural resources.

At the *first stage*, a thorough analysis of natural resources production, use, renewal and conservation should be carried out, i.e. the natural resource potential and environmental conditions should be evaluated. Such analysis should include investigation of the state of the given aquaterritory plus economic substantiation of the main directions of possible improvements in resources management, and the compliance of the natural resource potential of the aquaterritory under review with its traditional role in the national economy of the country concerned.

At the *second stage*, based on analysis of natural conditions and the current state of natural resources production, use, renewal and conservation, directions of re-specialization of the aquaterritory in the regional division of labour should be outlined, ways of improving the aquaterritory's structure should be suggested, and constraints on the production of particular types of resources and on the location of industrial enterprises should be determined.

For example, the development of the concept of marine ecosystem resources management in Kamchatka over the long term was a stage-by-stage process, based on scientifically substantiated forecasts for individual types of marine ecosystems.

Firstly, we substantiated preliminary work on the development of fishing in the coastal zone: detailed investigation of ecosystem resources in the waters of the Russian Pacific, and selection of locations for fishing harbour facilities, coastal fish processing plants and fish farms. At this stage, measures aimed at eliminating the disproportion in fishing and fish industry development in the region (resulting from "command–administrative" economic development) were elaborated and implemented, including construction of new, and reconstruction of existing ship-building and ship-repairing facilities, and producing and processing enterprises, along with expansion of the scientific and experimental base.

Secondly, we planned large-scale production of marine ecosystem resources in the Russian coastal zone, reconstruction of harbour facilities for the fishing fleet, construction of modern fish hatcheries and fish farms, biostations, spawning grounds and fattening areas, and reconstruction of fish-processing plants and servicing enterprises.

Thirdly, the construction of mechanized and automated industrial complexes for deep processing of marine ecosystem resources was envisaged for the purpose of complete saturation of the market (in both the Far East region and other regions of Russia, as well as in Japan) with high-quality sea products. The construction of a common transport line network was also planned.

At this stage, we also envisaged radical changes in the methods of comprehensive marine ecosystems' management, paying special attention to industrial development on the basis of rational production, use, renewal and conservation of fish resources, with the introduction and improvement of artificial reproduction of valuable fish species, to increase their productivity. Fish farms, at which the valuable fish are cultivated, should, according to these plans, become more and more important in the development of the fish industry in the Far East region.

When evaluating the resource basis for aquaterritory development, in addition to marine ecosystem resources, mineral resources, raw materials, fuel and power resources, secondary raw materials, and land, soil, water, forest and recreational resources must be analyzed in line with the environmental peculiarities of the given aquaterritory.

In the *third stage* of elaborating the natural resources management strategy for the aquaterritory, trends in the production, use, renewal and conservation of natural resources, the degree of proliferation and effects of negative processes and phenomena, and the damage caused by atmosphere and coastal water contamination, erosion of shoreline soils and their salination and pollution with industrial waste should all be investigated. Deterioration of forests and reduction in their area, and decrease in the biological productivity of the aquaterritory (including fresh-water bodies) and coastal forests must be also analyzed. The zones of the aquaterritory which are most heavily contaminated should be identified. And finally, the most unfavourable (from the environmental point of view) regions should be distinguished within the investigated aquaterritory.

Let us now analyze the basic principles of elaborating the development strategy for an aquaterritory.

The first and most important one is the *principle of load distribution.* The economic load on the aquaterritorial ecosystem at which irreversible changes do not occur is adopted as the basic load. Different loads entail different degrees of ecosystem depression. The economic load can be classified as "low" when the natural complex can sustain higher loads without losing its self-regulation capacity. The maximum possible economic load resulting in a higher degree of depression is considered as "stable". If the aquaterritory ecosystems overstep the limits of stability, the economic load affecting it should be regarded as "dangerous". In this case, the resultant depression can be described as "critical". The last stage of depression – "disastrous" – corresponds to the highest load on the ecosystem, leading to disturbances of the links between its natural components and to irreversible changes.

The second principle to be analyzed is the *principle of coordinated development.* The development strategy should be based on identifying and solving practical and scientific problems. At the same time, the aim of the development strategy is to create the most ideal research instrument for ecologonomic investigation of the aquaterritory.

The third principle is the *principle of stage-by-stage strategy elaboration.* A labour-consuming and multi-aspect problem of the development strategy cannot be solved in any other way than by stage-by-stage research in the realm of natural resources production, use, renewal and conservation, and application of the results in the practice of natural resources management. Each stage should result in one of the three objectives:

- identification of a new scientific problem or research method;
- development of a new technology to prevent environment contamination;
- elaboration of a new means for management of natural resources that were previously considered inaccessible.

Elaboration of the development strategy involves progressive movement from particular research problems and methods, investigated by individual scientists or research teams, to the integrated problem formulated in the development strategy.

The fourth principle is the *principle of openness and enlargement.* Each method should be open for use in all relevant ecologonomic studies. Results obtained from using a certain method in one of research sphere should be suitable for inclusion in investigations carried out in other spheres. Openness also means that the appearance of new approaches to be included in the development strategy – which, in turn, must be elaborated on the basis of the ecologonomic approach – should minimize expenditure on its practical implementation. However, the possibility of including new tasks in the strategy does not mean any voluntarism in favour of the solution of any problem of production, use, renewal and conservation of a particular type of natural resources within the investigated aquaterritory.

The fifth principle that deserves attention is the *principle of succession.* All the results obtained in the preceding stages of the research, should be available for comparison and "secondary" application in the subsequent stages. It goes without saying that this principle will be true and applicable only when the aforementioned results are obtained within the limits of a single aquaterritory. If other aquaterritories are involved, the succession cannot be guaranteed because of possible differences in the principles of their organization and resources management, and because of the specificity of their natural conditions.

The last but not least principle of the elaboration of resources management strategy and development for the aquaterritory is the *principle of practical applicability.* All studies should be oriented toward the solution of practical problems. This principle envisages not only mastery of the research tools, but also constant readiness for their practical application. The ultimate "user" of the strategy is the local administration of a particular part of an aquaterritory or, often, the whole of it. The strategy of natural resources management must therefore become the solution of the overall problem – preservation of ecological balance, ensuring, in the long run, stable economic development of the given aquaterritory. Therefore, the criterion of a research technique's suitability for practical application should include two basic components: the motivation of the work and the sufficiently high scientific credentials of the researcher.

Provided all these principles are adhered to, we can pass on to *the fourth and final stage* of the elaboration of the development strategy – the stage of forecasting, based on the continuity of regulatory methods in the aquaterritory development and comparability of parameters, used in the analysis and forecasts. The elaborated development strategy should become a guideline for natural resources management in the given aquaterritory.

Let us now ask ourselves: what are the main priorities of the strategy of natural resources management in the aquaterritory? In accordance with all the above, the priorities can be classified in two groups:

- those pertaining to the marine environment itself;
- those pertaining to the application of the ecologonomic approach in the practice of natural resources management in the region under consideration.

Priorities in the process of aquaterritory natural resources management are determined, primarily, by market demand for certain types of resources and the finished products obtained from them. Our objective in this sphere will be the most complete and rational utilization of these resources under the conditions of minimized ecological damage, to meet the requirements of environmental compatibility of the existing and newly constructed enterprises in the aquaterritory. For this reason the determination of aquaterritory resource specialization is extremely important to the aquaterritory development.

Going back to our case study of elaborating the strategy of natural resources management of the Kamchatka aquaterritory, we repeat that as a resource specialization of this region we selected the resources of the Pacific coast marine ecosystems. [133]. Thus, the economic efficiency of the fishing industry development in this region can be ensured by:

- stabilization of the volume of extracted resources;
- rational processing and use of the resources;
- effective operation of the main industrial production assets, primarily fishing vessels and other devices for the harvesting, processing and marketing of fish stock.

Until the present, fishing in the Far East region was organized in the form of large harvesting expeditions, traditionally including:

(1) fishing (harvesting);

(2) admission of caught fish on-board the fishing vessels;

(3) processing of fish resources and manufacturing of finished products from them;

(4) transportation.

However, the fact remains that such a procedure can be applied only to the harvesting and processing of large fish stocks. A careful analysis of the organization of fishing in the coastal zone of Kamchatka, however, has not revealed any differences between traditional expeditional fishing and the way in which the fishing process is organized in the coastal waters of the Kamchatka Peninsula, except that only the stock concentrated in certain areas was fished. Therefore, while ecosystems located in the areas of over-fishing suffered from an extremely high production load, stocks in other areas of the coastal zone were not fished at all – or else the production load on them was very low.

The problem of the so-called "additional catch" also remains unsolved: traditionally, the greater part of such "additional" fish (i.e. belonging to species differing from the majority of fish in a given catch) are processed into fish flour.

Our investigations have shown that optimization of the production load for all fish stocks involved cannot only ensure an increase in the amount of fish harvested in the Russian

200-mile economic zone, but can also entrain more types of fish in production. The same is true for other marine ecosystem resources: stabilization of the production load can increase the biological productivity of the Kamchatka coastal ecosystems.

In order to realize this idea in practice, we recommend that traditional expeditional fishing be ceased and that coastal fish harvesting be intensified, followed by processing of the catch within the coastal zone, which will require the construction of new plants for processing marine ecosystem resources on the coast.

We have found out that four types of fish are important for the development of fishing in the Russian Far East region: salmon, Alaska pollack, ivasi and herring. Although, according to our forecasts, the shares of these types of fish should decrease, their impact on the development of fish industry as a whole will remain perceptible.

We considered that about 99% of Alaska pollack (to say nothing of salmon, ivasi and herring) would be used as raw material for production of fully cut fish products, involving the utilization of eggs and liver. The cost of the finished products prepared from fully cut Alaska pollack is 30–40% higher than that of non-cut, and the introduction of new cutting technologies will ensure optimum use of the available refrigerator rooms on-board special fish-processing vessels and fish-processing plants in the coastal zone.

Canned Alaska pollack is not in demand on the market, that is why we suggested using up to 40% of the raw fish to produce fillet and stuffing. In our opinion, stuffing production is the best use of Alaska pollack. Products manufactured from Alaska pollack stuffing with the use of up-to-date technology are much in demand in the Japanese market.

The main trend in the use of salmon is the manufacture of freshly salted and mid-salted products, which are popular in Russia. We recommend allocating 75% of the total salmon caught, or artificially produced at fish farms, for this purpose and up to 60% of ivasi. As for herring, we suggest using it in small-packaged preserves.

While elaborating the regional development strategy for Kamchatka, we analyzed two scenarios – extensive and intensive.

The first scenario for developing the fish industry in the Kamchatka region aquaterritory can be characterized as inertial, based on the expansion and improvement of oceanic fishing. The further development of the fish industry, in this case, will be ensured by the improvement in market mechanisms of managing the regional economy, which will eliminate disproportion in the development of the various branches of the fish industry and redistribute marine ecosystem resources between joint-stock companies engaged in resources production.

The second scenario – the scenario of intensive development – can be introduced by including resource processing and resource conservation components in the structure of the fish economy. Taking into account the importance of Kamchatka rivers for salmon reproduction, we consider it necessary to implement careful scientific feasibility studies of constructing new industrial and agricultural facilities in the river basins where salmon natural spawning grounds are located. Ecological expert analysis is required to compare the direct economic effect of the construction of new industrial objects with the effect of traditional use of marine ecosystem resources. The former should not be overestimated with respect to the latter.

Experience of the industrialization of coastal areas shows that it causes damage primarily to fishing, which is based on the use of marine ecosystem resources that are very sensitivity to the depletion of their habitat. This is especially important for salmon. Therefore, we recommend introducing a special category of additionally protected natural aquaterritorial areas in the regions of Kamchatka which are of special importance for fishing. Within such additionally protected zones, economic activity would not be restricted (unlike in reserves), but new requirements would be made to natural resources management, that all economic measures be implemented in such a way as not to endanger the natural renewal of marine ecosystem resources. If damage is caused, it should be immediately compensated for by the implementation of special measures. Natural resources management in such zones would involve rational production and renewal of marine ecosystem resources by means of natural landscape preservation.

The creation of additionally protected zones within the Kamchatka aquaterritory and the introduction of a special resource management regime within them should enable the elimination of discrepancies in the economic development of the region as a whole.

We recommended creating such zones in other regions of the Russian Far East. In addition to generally increasing the economic efficiency of the production sphere in each region, resource specialization will ensure the improvement of the production, use, renewal and conservation of marine natural resources of the Russian Pacific coast, including its marine ecosystem resources.

When elaborating a strategy of natural resources production, use, renewal and conservation in the given region, we should analyze various links within the given aquaterritory. The first type of links to be considered is local links, which include:

- links between enterprises producing natural resources within the given aquaterritory;
- links between resource-producing and resource-processing enterprises located within the same aquaterritory.

Analysis of these links can be useful for data processing and the unification of environment monitoring instruments and techniques.

Interregional links are links between aquaterritories within the limits of one country or a group of countries. They comprise links with land areas and water areas adjacent to the investigated aquaterritory, whose pollution can affect the environmental conditions of the aquaterritory. Interaction between the aquaterritory and its adjacent areas is realized within the framework of the joint use of biological resources.

And finally, there are global links, understood as the organization of natural resources management in accordance with research on a global scale. These links are characterized by different forms of organization, including setting up national parks and reserves, which are parts of a global system of environment conservation (implying different forms of financial participation by different countries).

The links described characterize the *communication criterion* involved in elaborating the strategy of natural resources management and economic development of the aquaterritory in question. Another, no less important criterion is the *integration criterion*, which should ensure the transfer of data base, methodologies and technologies based on intra-aquaterritorial specialization. The following degrees of integration can be singled out:

- integration based on information about existing methods of natural resources management and environment conservation;
- integration within the framework of the problem solved for a specific type of resources;
- integration within the problem of the development of the whole complex of aquaterritorial natural resources.

The third criterion – the *criterion of efficiency* – concerns the easiest way to implement a certain method, taking into account the available financial resources.

Elaboration of the aquaterritory development strategy requires a balance of tactical aims for today with aims for the distant future. The limits of ecological–economic forecasting must be determined from the achievements of scientific and technological progress. The coordination of tactical and strategic aims of national economic development with the purpose of rational management of natural resources should be implemented constantly at all levels of elaborating the development strategy, and corrected according to the results of scientific and technological work in the relevant sector. The main criterion of the viability of the strategy is the preservation of ecological balance within the given aquaterritory.

Elaboration of the strategy of marine natural resources production, use, renewal and conservation at the regional scale should, in our opinion, become the basis for the management of economic development not only of individual aquaterritories, but also of the whole World Ocean.

For example, in the fish industry, the current state of marine ecosystem resources production is the critical factor in increasing its efficiency. All attempts to specify parameters of productivity of individual marine ecosystems are aimed primarily at distinguishing the contribution of natural factors to the volume and quality of finished products, and in the long run can promote increasing economic efficiency of the manufacturing of finished products.

In addition, the development strategy should necessarily take into consideration the rate and achievements of scientific and technological progress in the relevant branch of the national economy.

Development of the strategy of marine natural resources management in a region is implemented within the framework of the ecologonomic approach. In the process of regional strategy elaboration it is necessary to correctly distinguish the aquaterritory as an object of research. Thus, the information presented in this part of the book relates closely to section 1.3, dealing with problems of ecological–economic regionalization.

Given that the strategy under consideration was elaborated by us for several coastal regions of the Russian Far East at the request of local administrative bodies, we cannot present any concrete data, because the right of publication of statistical data in the public media belongs exclusively to the respective regional administrative bodies. However, the general scheme, principles and criteria of elaboration of regional development programs are universal and can be applied for any region of the world.

5.5. Monitoring of Marine Environment Conditions and Marine Ecosystem Resources

At the International Conference on Environment and Development (Rio de Janeiro, 1992), the necessity of creating a global system for observing the World Ocean, including its coasts, was emphasized [33]. Monitoring of the marine environment is indispensable for the solution of one of the most acute ecological problems – identifying the roles of natural and anthropogenic factors in changes occurring in the natural environment [134].

In general, we understand *ocean monitoring* as a comprehensive system of observation, estimation and prediction of changes in the aquatic environment and marine ecosystems caused primarily by human impact.

Over the past two decades, our ideas of objectives of environment monitoring have become more precise. One of the latest (and, probably, most complete) definitions of monitoring is presented in the *Popular Biological Dictionary*, published in Russia (Nauka, Moscow) [135]. In our opinion, it reflects most completely and precisely the essence of the monitoring process. *Monitoring* is defined as the tracking of certain objects and phenomena, including those of a biological nature. In its most complete form, monitoring employs a multipurpose information system, aimed, primarily, at observation, evaluation and prediction of the state of the natural environment under the effect of human impact, and designed to warn of possible critical situations (increased gas concentration in the air, etc.) that might be harmful to human health, the well-being of other living creatures, their communities, and abiotic, natural and artificial objects, processes and phenomena [135].

Monitoring systems can be classified in terms of various parameters:

- sources of impact upon the natural environment;
- response of the main components of marine ecosystems to these impacts;
- methods of observations, etc.

A system of monitoring that takes into account both biological and geophysical aspects seems to be the most suitable for the solution of ecological and economic problems within the framework of the ecologonomic systems theory we have suggested.

Therefore, *ecological monitoring* is monitoring that involves observation, estimation and prediction of anthropogenic changes in the state of marine ecosystems, including variations in the degree of marine environment contamination and the response of marine ecosystems to such changes. Therefore ecological monitoring involves:

- monitoring of sources of impact;
- monitoring of chemical, physical and other influential factors;
- monitoring of the response of different components of marine ecosystems to human impacts.

Such monitoring can be global, i.e. implemented on a global scale, or regional, involving observation of ecosystems within the limits of a particular sea basin or region.

Our concept of ocean monitoring is based on the results of investigating marine ecosystems' functioning. Within the framework of the ecologonomic approach, the ocean monitoring system should be based on joint analysis of economic and ecological criteria of the state of the ocean ecosystem.

Contact zones (e.g. the land–sea contact zone, water–air interface, water–sediment interface) deserve special attention in monitoring, because the intensity of toxic substance accumulation in these zones is higher that in any other zone of the World Ocean, and processes of pollutant transformation occur quicker in them than in the water column or the atmosphere. This is explained by the details of chemical and biochemical reactions at the phase interface [136].

The creation of optimum monitoring systems for evaluating and forecasting marine ecosystem resources requires further investigation of:

- the role of atmospheric pollutants' transportation in contamination of the World Ocean and its effect on processes occurring in the contact zone (water–air interface) and on the functioning of nekton biocenosis;
- dynamics of marine environment contamination;
- biochemical cycles of pollutants in marine ecosystems and the identification of "critical" zones in the ocean (in terms of duration of pollution effect), taking into account the effect of all natural factors;
- patterns of marine ecosystems' functioning in conditionally clean and contaminated aquatic environment.

It is now clear to everybody that in the future the role of the ocean in human economic activity will increase, and the marine economy will become one of the most important branches of the world economy. It goes without saying that human impact on the ocean will therefore be intensified [137]. That is why it has become vital to develop scientific principles for monitoring this.

From the point of view of biology, the best indicator of the condition of marine ecosystems is the state of the various organisms composing them. Using representative components of the marine ecosystem as test objects we can obtain the integral effect of numerous factors. It is important to specify not only the intensity of the effect of a particular factor in absolute units (many of them, such as water temperature, density, transparency, illumination, turbidity, and dissolved oxygen content, can be measured using special instruments), but also the degree of the negative (disturbing) impact of this factor on the investigated marine ecosystems. In addition, the disturbing factors do not affect a marine ecosystem separately, but together, and their combined effect can turn out to be more pronounced than the sum of the impacts of individual factors.

It is necessary to use several test objects, each of them possessing special sensitivity to a particular factor, in order to identify the factors affecting the given marine ecosystem. In the future, it will also be necessary to develop a standard set of such test objects.

As an example, let us consider marine algae. They are often used for the purpose of marine environment monitoring, because most of their species are stenotypic and highly sensitive to changes in ambient conditions. The degree of sea water contamination as one of the indices of marine environment quality can be determined with the help of algae:

(1) using them as indicator organisms;

(2) comparing algal community structure in areas with different degrees of pollution and in the test area.

In the first case, the presence or absence of indicator types or groups of algae and their population allow us to refer the whole habitat of the given marine ecosystem (or its individual areas) to a certain type of water. In the second case, the conclusion is based on the results of comparing the types and quantities of algae in different zones of the marine ecosystem's habitat.

Processes of degradation in different marine ecosystems have their own unique features, depending on the factors affecting them. Therefore, analyzing the state of a particular ecosystem, we can determine the negative factors that have affected it, and the intensity of such negative effect.

The same is true for processes occurring at the cellular level. Any cell of any living organism can accumulate toxicants, whose effect it is subject to at a given moment in time. Having identified an alien substance in the cell of an indicator organism, we can make an unambiguous conclusion about the penetration of this substance into the marine ecosystem and its habitat.

Among numerous systems of sea water classification according to indicator algae, the system of saprobility indices – assigned to waters in accordance with their degree of pollution with organic substances and products of their decomposition – is most widely used. The system of saprobility indices, suggested by P. Kolvitz and M. Mareson in 1908, and its later modifications are highly valued by both biologists and ecologists. Kolvitz and Mareson considered the degradation of organic matter found in polluted waters to be a stage-by-stage process; according to the degree of organic pollutants decomposition, waters can be referred to different saprobility categories: polysabrobic, mesosaprobic and oligosaprobic [67].

In the *polysabrobic zone*, around the place of pollutants' discharge, cleavage of proteins and carbohydrates occurs under anaerobic conditions. This zone is characterized by the absence of dissolved oxygen, presence of undegraded proteins, much hydrogen sulfide and carbon dioxide in the sea water, and the reducing type of biochemical reactions. Only a few species of algae can survive in this zone, but the number of individuals of each species found here is large.

In the *mesosaprobic zone* pollution is less pronounced than in the polysabrobic zone. In the mesosaprobic zone there are no undegraded proteins, little hydrogen sulfide and carbon dioxide, but there are low-oxidized nitrogen compounds (e.g. ammonia). This zone can be subdivided into alpha-mesosaprobic and beta-mesosaprobic subzones. In the alpha-mesosaprobic subzone there is much ammonia and more dissolved oxygen than in the polysabrobic zone; blue-green algae *Oscillatoria vanch* and *Phormidium kutz* are found here. Decomposition of organic matter proceeds due to aerobic bacterial oxidation. The beta-mesosaprobic subzone is characterized by the presence of ammonia, nitrous acid and nitric acid. The content of hydrogen sulfide is low. Organic matter is decomposed due to bacterial aerobic oxidation, because the concentration of dissolved oxygen in the water of this subzone is sufficient to maintain the vital activity of aerobic oxidizing bacteria. The species diversity in the beta-mesosaprobic subzone is higher than in the alpha-mesosaprobic zone, but the quantity of organisms is less and their total biomass is less. Diatomic and green algae are most frequently found here.

In the *oligosaprobic zone* the water is relatively clean. There is no hydrogen sulfide, little carbon dioxide and practically no dissolved organic matter, and the concentration of dissolved oxygen is close to normal. Considerable species diversity, numerous organisms and a high biomass value are typical of this zone.

Owing to the fact that the indicator value of many algal species depends on the conditions in which they occur, it is necessary to take into account not only the presence of the particular species serving as saprobility indicators of water, but also the quantity of organisms of each indicator species and its ratio to the number of individuals of other species within the given marine ecosystem. Some additional indices are required to enable a better selection of particular algae as saprobility indicators. Thus, it is necessary to take account of data on the state of populations of indicator organisms, their morphological and age-related peculiarities, and the occurrence of deformity among them. One of the most realistic ways to improve the ecological monitoring of marine ecosystems is to develop special tests to control the state of algal populations on the basis of their morphological parameters.

Biological analysis of sea water is necessary to set up a system of ecological monitoring for marine ecosystems. This analysis should be implemented on the basis of investigating the details of changes in species diversity and the quantity of indicator organisms, their physiological and morphological peculiarities, and disturbances in oxidation and/or production–destruction processes. Results of such analysis should be presented in digital form as codes, matrices or indices, e.g. indices of saprobility, indices of species variety, Wouviss bioindices, Schendler points, etc.

Algae can be used to determine the toxicity of different substances that find their way into the marine environment, such as heavy metals, detergents, pesticides and others. Results of marine algae investigations can help us obtain scientifically substantiated MPC values for any pollutant. Blue-green algae are the most frequently used for such toxicological analysis.

In addition, marine algae are important participants in the process of marine environment self-purification and are relevant to the improvement of sanitary-hygienic conditions of sea basins, and water quality formation in general. Thus, the process of sea water enrichment in oxygen, released by algae through photosynthesis, is vital for many processes of biological self-purification involving organic matter oxidation. In addition, metabolites released by algae through their vital processes also play an important role in water quality formation and changes.

Algal cells can quickly absorb various chemicals from the sea water. The ability of algae to accumulate radioactive substances deserves special attention. Phytoplankton is a kind of trap for radionuclides: it absorbs most radioactive decay products, such as ^{90}Sr, ^{95}Zr, ^{106}Rh, ^{131}I, ^{137}Cs and ^{144}Ce [138]. Under certain conditions, dead algal cells do not differ from live ones in retaining radioactive substances. In other cases, the degree of radionuclide absorption by dead cells is less than the absorption by living cells. The ability of certain algae to accumulate various chemical substances and radionuclides in their cells and hold them fast there allows us to use such algae in special systems of waste water treatment (deactivation systems).

Let us emphasize once more that *ecological monitoring* is a system of long-term observation, evaluation and prediction of marine ecosystems' conditions on the basis of established criteria and indicative parameters. As was mentioned earlier, the *objective of ecological monitoring* of the marine environment is to identify anthropogenic changes in marine ecosystems, which can be achieved by periodically measuring certain parameters of the investigated marine ecosystem.

Ecological monitoring involves data collection (observation), data processing, and experiments. Based on the analysis of the data collected (or on experimentation), we can diagnose the state of marine ecosystems and predict its variation.

Observation is the main form of *diagnostic monitoring*, registering various parameters that characterize a marine ecosystem's state at the current moment in time. A system of such diagnostic monitoring should involve observations of various biological parameters that are expected to respond to anthropogenic impact (e.g. changes in the numbers of certain plant, animal or bacteria species, modification of the species' structure of the community, etc.). The manifestations of their response should be considered as the response of the ecosystem to disturbing impacts (occurrence of deformity, impairment of morphological parameters, etc.).

In our opinion, algae should be widely used as indicator organisms in ecological monitoring, because physicochemical methods of determining marine environment conditions, used on their own, cannot reveal the possible response of marine ecosystems to various anthropogenic effects. Therefore, methods of biological analysis involving the use of algae (owing to their stenotypic character and high sensitivity to changes in marine environment conditions) are very important. Marine algae are good test objects for diagnosing sea basin pollution (including contamination with oil, oil products and radionuclides).

In selecting indices for ecological monitoring, various methods should be used to reveal the response of algae at different levels of their biological organizations – subcellular, cellular, organism, population and biocenotic. At the subcellular and cellular levels, primary disturbances in biochemical mechanisms and molecular structures in the living cell, caused by environmental pollution, are registered. At the organism and population levels, morphological disturbances in individuals and whole generations are revealed. At the population and biocenotic levels, the restructuring of natural communities, changes in their productivity and resistance to the given impact can be traced.

All the biological parameters fall into two categories:

(1) functional, which can be expressed by a derivative over time; i.e. as the rate of change in a certain function (productivity, etc.);

(2) structural, which can be expressed as an integral of time, i.e. as a certain result of actions by the time at which the parameters are registered (e.g. biomass, number of species, organic matter content in the ecosystem, etc.).

The role of integral averaged characteristics of ecosystems is acquiring ever-greater prominence in ecological monitoring. Remote-sensing methods (the most useful and representative ones) should be applied in ecological monitoring, where possible. In remote-sensing monitoring, phytoplankton is traditionally used as an indicator of biological productivity in the given sea basin. The absorption and fluorescence characteristics of chlorophyll *a* in the visible part of the spectrum are the main parameters that serve as the basis for remote-sensing probing of phytoplankton [139].

Experiment is the main methodological basis of *prognostic monitoring*. Collection and processing of input data, facilitating the identification of trends in marine environment change, enable us to set up such experiments, the results of which can help predict biological consequences of human-induced changes in environmental conditions.

The forecasting of the state of marine ecosystems and the identification of trends in their variation are relevant to planning natural resources management, not only for the given marine ecosystem, but also for the entire sea in which the ecosystem in question is located. It is therefore very important to develop a theory of forecasting changes in marine ecosystems that are subject to anthropogenic impact of any type. In such cases, ecosystems of reserve zones can serve as reference zones for comparison.

In our opinion diagnostic monitoring in combination with prognostic monitoring is the main component of ecological monitoring to trace human-induced changes, and therefore the main component of ecologonomic forecasting. Thus, the monitoring system is multiobjective.

Note that today the role of information obtained from monitoring in managerial decision making is not quite clear. We adhere to the view that the monitoring system should be regarded as part of the economic complex, promoting the development of the national economy. It is important that monitoring data be taken into account in solving economic problems. The problems of organization of marine environment and monitoring of marine ecosystems are the key problems of marine ecologonomics.

To illustrate all this, let us analyze a case study of ecological monitoring implemented for the basins of the southern seas of Russia.

At present it often turns out impossible to make a realistic assessment of the changes occurring in the Aral, Caspian, Azov and Black Seas. There is no available information for this and no existing system of ecological monitoring. It is safe to say only that in these sea basins we are faced with a very complicated (in some places critical) ecological situation. It is necessary to undertake urgent and efficient nature conservation measures, whose scientific substantiation is impossible without a reliable system of ecological monitoring.

Generally speaking, the development of the scientific fundamentals of marine environment control and their practical implementation, aimed at preserving the resource potential of marine ecosystems, necessitates the creation of a new monitoring system in Russia, which would unite all the existing monitoring and information systems, which are now organized along departmental lines: hydrometeorological, geological, fishery, sanitary-epidemiological, etc.

In Russia, a State System of Natural Environment Observation has been set up, which is regarded as a part of the Global System of Environment Monitoring, created back in 1974. Such systems, in the long run, should have ensured a new level both of investigating natural phenomena and of decision-making competence in their management.

The experience of the last several decades proves that for the southern seas, monitoring was merely a formal accumulation of facts. Such a situation can be, to a certain extent, explained by the fact that the information system "of observation and analysis of natural environment, primarily pollution and effects caused by such pollution in the biosphere", suggested by Yu. A. Izrael in 1970 [140], was based on the concept of monitoring as a "registrator of facts". Information obtained within the framework of such monitoring was employed to control the state of the environment mainly by means of pollutant disposal standardization.

Today the investigation of environmental consequences of human economic activity in sea basins is carried out in two main directions. The first involves estimation of the sea water pollution level. The second is the analysis of the state of ecosystems under present conditions.

Because the concept of pollution regulation and standardization is widely used, and because one often comes across the term "accumulation capacity" in scientific literature and several attempts have been made to substantiate this term quantitatively [141], special attention should be paid to the following three consderations.

First, the value of the "accumulation capacity" is calculated only as the average for the whole water body. Therefore, even in cases when the value of pollutant flow coming into the water body turns out to be, on average, less than the maximum permissible value, it is highly probable that some parts of the water area will be very heavily contaminated (the concentration of certain toxic substances exceeding the MPC by dozens of times), whereas others may remain relatively clean.

Second, the spatial and temporal variability of contamination parameters for sea water areas cannot be estimated realistically on the basis of existing observation data. Stations of the State System of Natural Environment Observation can be grouped into different categories. All in all, there are 521 observation stations within the framework of the State System of Natural Environment Observation: six stations in the Aral Sea, 181 in the Caspian Sea, 82 in the Azov Sea and 242 in the Black Sea. These stations are unevenly distributed over sea water areas, being concentrated in certain areas of the coastal zone. Data obtained here cannot be evaluated using statistical methods: the number of observations annually made in each area varies from 10 to 150 (taking into account the number of sampling levels).

Third, we are compelled to doubt the substantiation of certain established standards (MPC values), because our knowledge of the nature of seas and their self-purification properties is restricted. Examples of unpredictable negative consequences of small levels of contamination (by today's standards for pollutant concentrations) can be given.

Note that none of our definitions of monitoring deal with the problem of the role of monitoring information itself in the mechanism of managerial decision making. However, there is a viewpoint [142] that the monitoring system should be regarded as part of an economic complex, promoting economic development. (Until recently the term "economic development" meant merely intensive increase of industrial potential.) Monitoring data on environmental conditions and their variation did not greatly affect the solution of economic problems. In addition, a tendency to interpret observation data in correlation with the ultimate goal of financing began to manifest itself against the background of shortage of primary observation data – which is only to be expected: science does not stand apart from society, and any unsolved set of problem will suggest numerous practical conclusions.

Traditionally, the system of natural environment monitoring has three components:

(1) observation of environmental conditions and factors affecting them. Note that almost all Russian scientific publications dealing with general problems of natural environment monitoring (such publications remain prevalent) assume that observation data obtained within the framework of such monitoring systems comply with an up-to-date level of scientific development. In this case, only some vague wishes to improve the observation network and measuring instruments are expressed.

(2) evaluation of environmental conditions for the current period.

(3) prediction of environmental conditions.

In our opinion, the management component must be added to this scheme, as in the case of surface water quality monitoring [143], which consists of:

- collection of representative input data for control of the state of water bodies;
- data processing aimed at the compression of information on the current state of water bodies and modelling of their possible variations (using an automated information system);
- water quality control by means of decision making and implementation in accordance with the types of activities and the intensity of "controlling impacts" (management component).

In the view of the ecologonomic approach to the investigation of seas, it is interesting to examine the terms "ecosystem monitoring" or "ecological monitoring" suggested by I.P. Gerasimov [144]. He considered the main objectives of such monitoring to be as follows:

(1) observation of changes in the main natural ecosystems forming the environment;

(2) observation of transformation of these ecosystems into natural–technological systems.

Such monitoring systems not only register natural and human-induced changes in the environment, but also help preserve ecological balance under conditions of intensive economic activity.

The suggested approach for the case under review involves ecological monitoring of the southern seas as integral ecosystems interacting with other adjacent natural systems, and analysis of the consequences of marine natural resources management and other types of human activity in these sea basins. The focus of the ecological monitoring of the southern seas should be their renewable natural resources used in human economic activity, and factors affecting such use.

The complicated character of processes occurring under certain natural–anthropogenic conditions, and appreciable difficulties in the organization and implementation of in-situ observations did not allow us to properly develop one of the main elements of monitoring – a scientifically substantiated observation system. At present, this system should include a clearly specified set of parameters to be determined, a scheme of spatial distribution of observation posts and the times at which observations are carried out at these posts (spatial and temporal arrangement of the observation network), and the required accuracy of measurements for individual parameters. Thus, when planning and implementing in-situ observations, there are two important considerations that must not be neglected. Firstly, the information obtained from the observation network is limited, being restricted by the network's spatial and temporal arrangement and secondly, errors can arise from non-standardization of techniques and instruments used for observations.

The main aim of ecological research on the seas under consideration can be understood as diagnosis of changes in their natural conditions under the impact of both natural and anthropogenic factors, including the making of ecological forecasts and corresponding practical recommendations. Such research should be carried out at the same time as studies on the basins of rivers flowing into these seas, and on the land–sea contact zones (deltas, coastal areas, frontal interfaces, etc.). Accordingly, the program of ecological monitoring, e.g. for the Caspian Sea region, may comprise two main parts: "deltas" and "coastal areas with no discharge" [145], within which inter-related complexes may be identified consisting of the following components in various combinations: river basin, delta, offshore part of the delta, shelf, open sea. Each of these complexes has its' own specific set of ecological problems, which cannot exist independently.

The existing network of stationary observation stations in the above-mentioned Caspian Sea region does not ensure that adequate information on the spatial and temporal variability of the parameters of the abiotic and biotic processes occurring here (especially those of human-induced pollution) is obtained to meet current requirements for such information. In the Caspian Sea, research vessels of the former USSR State Committee for Hydrometeorology and Environment Monitoring (Goskomgidromet) and Ministry for Fish Economy (Minrybkhoz) have been carrying out regular observations (mainly in summer) over standard cross-sections, the distance between stations often exceeding 50 km. The cross-sections themselves are located at a distance of 100 km or more from each other. Meanwhile, the synoptic eddies typical of the Caspian Sea have a diameter of 15–20 km, so the existing network of observation stations here cannot trace the effect of such eddies (which we now know is appreciable) on the formation of hydrophysical fields, and on parameters of pollution and bioproductivity, closely related to these fields [146].

Under such conditions, highly sensitive instruments for the control of water conditions, which are being developed and already in use in some places in Russia, cannot, in principle, ensure the desired outcome. Thus, for example, in the investigation of water quality, at present and for the near future, the water samples taken (discrete over both time and space) will probably continue to be the main source of information. If a sampling technique ignoring spatial and temporal variability in the investigated processes and phenomena is applied, this can lead to *a fortiori* larger distortions in the parameters, as compared with those that may occur in further analytical studies. In this case, considerable labour and financial resources, used for the development of up-to-date instruments and equipment, may, if the principles of measurement and the number of observation points remain unchanged, turn out to be wasted.

In the northern part of the Caspian Lowland, for example, irrespective of the gravity of the ecological situation, there is only one biosphere reserve in the Volga River delta. Its in-situ observation data cannot be regarded as representative of the north-eastern and north-western parts of the Caspian Sea coast. In the north-western area of the coast there are only three hydrometeorological posts (which do not carry out any biochemical or biospheric observations), and in the north-eastern part of the coast, from the Ural River delta to the Buzachi Peninsula, there is not a single permanent post where sea water level and meteorological parameters might be registered or pollution parameters measured.

For the southern seas, there is insufficient in-situ observation data. The quality of such data, as a rule, does not meet the requirements of modern standards. The replenishment of expedition data, even under the most favourable conditions (all the research stations working according to a common program), could hardly increase our knowledge of the spatial and temporal variability in the characteristics of the hydrophysical and other fields of water bodies. In addition, we cannot be sure that it will be possible, in the near future, to eliminate the drawbacks of expedition methods used today. However, new experimental data are relevant to contact zones characterized by the greatest degree of spatial and temporal variability in their regime parameters. These zones are sensitive to the impact of water resources management measures and their consequences. However, there are no vessels or measurement instruments for solving such problems. In these cases, wide use of remote-sensing methods of investigating water bodies and the adjacent land areas may be helpful, along with the use of a "testing-ground" approach to marine research.

Given the insufficiency of reliable and comparable instrumental observation data, the greater part of the information available is attributed to marine hydrophysics, i.e. there are more favourable prerequisites for studying and forecasting the sea's hydrophysical regime. Most probably, our present hypotheses on the structure and dynamics of sea waters is the only thing that can be regarded as offering a firm basis for ecological research.

Under such conditions, one of the first problems to deal with is an inventory of in-situ measurement data for marine environment parameters, including the quantity and composition of biota, and the properties of bottom sediment, especially for shoals where biological resources are concentrated and their intensive production is carried out. With the shortage of current experimental information, the role of historical monitoring (a data bank) becomes ever more important, especially for revealing the natural dynamics of various processes. However, for the Caspian Sea, for example, a common data bank, which would meet all current requirements, has not yet been created.

Ecological studies and monitoring of the southern seas could probably be improved by the development and modernization of existing observation services and traditional approaches. This would necessitate the following:

- generalization and critical analysis (from the common methodological standpoints) of all the available data concerning the nature of the southern seas and their resource potential;
- development of a system of priorities for managing marine natural resources;
- determination of a set of observation parameters to be included in ecological monitoring in accordance with the established system of priorities.

Within the framework of ecological monitoring, the observation system and in-situ observation data processing and analysis should be coordinated around the aim of evaluation and prediction.

In other words, ecological monitoring of seas, in addition to the observation system itself, should necessarily include systems of estimation and forecasting. Therefore, the observation system should provide data suitable for the solution of estimation problems (both from a purely technical point of view – the use of mathematical statistics, and classification of information in accordance with the needs of users – and from the viewpoint of identifying the problems that are most difficult to set, such as favourable or unfavourable conditions of the ecosystem, the availability and value of the assimilation capacity of water bodies), and input data for forecasting.

The selection of mathematical models for forecasting is largely determined by the available observation systems and data bank. The adopted models coordinate experimental information both according to its contents and according to the accuracy of individual measurements. Problems of ecological monitoring cannot be solved independently of developing a system of mathematical models: these are two sides of the same coin.

For example, our experience in mathematical modelling of hydrophysical processes in seas and big lakes shows that, at present, that the main difficulty is not the development and calibration of new models, but the concentration of labour and financial resources for the most optimum application of existing models, provided the data bank contains all the necessary information on the temporal and spatial variability of the water bodies' parameters.

It goes without saying that the ultimate goal of ecological monitoring – providing control over the state of the marine environment and non-exhaustive production of its natural resources – is closely related to the solution of the socio-economic and political problems facing the country concerned. These problems, in turn, affect the operation of the ecological monitoring system.

At the same time, operation of the monitoring system directly depends on the investigations carried out by numerous hydrometeorological, geological, geophysical, biological and geographical institutions. Although some such studies may not necessarily be included in the system of ecological monitoring, there should be concise coordination of the efforts of the scientists and specialists of these institutions for the purpose of solving monitoring problems. It is necessary to improve sampling procedures and methods of sample analysis in order to obtain sufficient and reliable information on the state of the marine environment. Comparison of the results of modeling with in-situ observation data will allow us to make conclusions about the adequacy of the models developed and to outline ways in which they could be improved and their costs could be reduced.

There is today no doubt that for the last several decades the regimes of the Aral, Caspian, Azov and Black seas have undergone considerable change. Human economic activity in sea basins has played the most important role here. The observed unfavourable changes are connected mainly with the decrease in river water inflow, disturbances in its seasonal dynamics, and sea water pollution from drainage, sewage and waste water. At the same time, degradation of aquatic ecosystems has taken place, usually accompanied by significant reduction in the ecosystems' biological productivity; moreover, recreation and sanitary conditions in the coastal zones have deteriorated. The climate in the regions adjoining the seas has changed too, and in some cases negative socio-economic consequences have begun to appear.

The observed decrease in river water inflow to the seas (10–13% reduction for the Black and Caspian Seas, 25% for the Azov Sea and nearly 100% reduction for the Aral Sea, compared with the original inflow values), even if it is caused entirely by human impact, constitutes, as we see it, only a fraction of its total value. It is hardly possible to comment on the direct impact of river runoff losses on the main regime parameters of the whole water body regime (e.g. the average currents). This conclusion turns out also to be true for certain areas in the seas under review, for example for some areas in the north-western part of the Black Sea and in the northern part of the Caspian Sea which are, to some extent, independent. In these areas, the pattern of sea water properties distribution is subject to comparatively minor spatial and temporal variations under the effect of fluctuations in the volume of continental water inflow, with the exception of regions subject to the direct impact of river runoff, such as brackish lagoons and water areas adjoining large river deltas. In any case, human-induced reduction in river runoff, and changes in seasonal runoff dynamics especially affect the vertical and horizontal distribution of sea water salinity – in both shallow and deep-water zones of the southern seas. Disturbances in historically established water stratification result mainly from the transformation of the southern seas regimes under conditions of anthropogenic stress. This stress modifies the gas regime (anoxia and mass destruction have now become typical on shelf areas and the continental slope) and the biogenic substance balance. Human economic activity, as a rule, leads to decrease in river runoff and, at the same time, to increased input of pollutants flowing into the seas with river water.

The scale of undesirable changes in the aquatic ecosystems of the southern seas varies over a wide range. For example, one historically established ecosystem of the Aral Sea has totally degraded. It is impossible to restore the Aral Sea to how it was 30 years ago. The sea cannot be saved even at its current lower water level. Given the lack of uncontaminated fresh water inflow, all we can do is to prevent further shrinking of the surface of this water body, which, at present, can hardly be called a "sea", where increased pollution (mainly with pesticides and herbicides found in drainage waters) threatens to destroy all life.

In analyzing the problems of monitoring the southern seas of Russia, we consider it expedient to discuss the problems of the Black Sea in detail, because, unlike the Caspian, Aral and Azov Seas, the coast of the Black Sea is the only maritime resort area in the warm climatic zone which is accessible to citizens of Russia and the other CIS states. The Black Sea has an indispensable value for local people – economically, socially and culturally; most people in the former Soviet Union simply cannot afford to go on vacation to the exotic coasts of warm seas and oceans in Greece, Cyprus, South America, Africa or the Canary Islands.

The Black Sea is a semi-enclosed sea with a surface area of 420,000 km^2. It now has seven coastal states; some of them are highly urbanized and industrialized, and all employ intensive agricultural practices.

The ecological and hydrological conditions of the Black Sea are quite unique and its flora and fauna are very sensitive to changes in the composition and temperature of the sea water. Ninety per cent of the Black Sea basin is anoxic and this proportion rises continually, particularly in the middle parts of the basin, due to an increasing inflow of organic pollutants. In addition, we must emphasize that, in the Black Sea, changes in the abiotic and biotic components of the environment manifest themselves mainly in the shelf area. Their manifestations are less pronounced in the open part of the sea, because of the peculiarities of its water circulation.

The Black Sea receives large quantities of domestic and industrial waste water in untreated form. Major pollution sources are rivers flowing into the sea, especially in the eastern and north-eastern parts of the coast (Russia, Ukraine, Moldavia). The amount of pollutants transferred through the Bosporus is unknown, but the contribution of Turkish rivers in pollution is undoubtedly less than the contribution of the eastern part of the sea coast.

The state of the environment in the marine and coastal areas of this delicate ecosystem have become worse during the last few decades, owing to a dramatic increase in economic activities in the region as well as in continental Europe and Asia in general. The Black Sea states have a great interest in the protection of the marine environment and coastal areas against adverse environmental effects, and in conservation and sustainable development of the sea's and coast's natural resources and amenities.

Each coastal state implements some environmental measures in its coastal areas but these are clearly insufficient to correct the degradation of the Black Sea. International action is urgently required to overcome the pollution problem.

The coastal states have made an attempt in this direction by negotiating an agreement for environmental protection in the Black Sea. Negotiations started in 1988 and yielded the draft Convention for the Protection of the Black Sea against Pollution, and three protocols: the Protocol for the Protection of the Black Sea Environment against Pollution from Land-Based

Sources, the Protocol for the Protection of the Black Sea Environment from Pollution due to Dumping, and the Protocol Concerning Cooperation in Combating the Pollution of the Black Sea Marine Environment by Oil and Other Hazardous Substances in Emergency Situations. Although the text of the Convention was completed in 1991, it was not opened for signature then. This Convention (when signed) will provide a vital mechanism for solving environmental problems pertaining to the Black Sea, and its Commission could serve as an intergovernmental body to address the environmental issues in the region. We believe that riparian countries should sign this Convention as soon as possible and ensure that the Convention becomes a viable mechanism.

In order to accelerate action, the government of Turkey has commenced an initiative for starting a regional environment project in the Black Sea with the participation of all the riparian countries. The proposal to initiate such a project was conveyed to the Executive Committee of the Global Environment Facility (GEF). Recently the GEF Executive Committee approved the proposal unanimously. This proposal has received support from various countries including the coastal ones and from international organizations. The project will start as soon as the sponsors of the facility endorse it. The proposed project includes preparatory work on determining the degree of environmental pollution and degradation. It will also assess the institutional, administrative, scientific, technical, technological and methodological needs for an effective and practical management program, and identify priority investment needs for the protection of the environment in the Black Sea's marine and coastal areas. Members of the Executive Committee, namely the United Nations Environment Programme, the United Nations Development Programme and the World Bank, are working with the national authorities of the coastal countries to prepare the project.

Progress on the restoration of the Black Sea has been very limited so far. With the exception of Turkey, the degree of economic development in the coastal states restricts the authorities from implementing major anti-pollution measures to limit the inflow of pollutants. In some countries, attempts are being made to limit the degradation of coastal waters, but, clearly, urgent international actions, with effective technical and financial assistance, are needed to rescue the Black Sea. Among these actions, cooperative efforts to reduce pollutant input from the River Danube would help to solve the problem.

Together, the Convention and the proposed project, if implemented soon, will make possible a response to environmental threats that are jeopardizing public health as well as natural marine and coastal resources of great economic and social value to the countries of the region.

Today, it remains impossible to monitor the Black Sea ecosystem as an integral unit, so it is difficult to identify with certainty the consequences of human impact against the background of natural variations in the ecosystem. This is probably the main reason for contrasting estimates of the same phenomena, with some specialists proclaiming an ecological disaster in the Black Sea ecosystem, while others, knowing that most of the data on disturbances in this ecosystem are connected with natural fluctuations, accuse the former of "ecological hysteria". As always, the truth is between the two extremes: it is still too early to speak of an ecological catastrophe, but the state of the Black Sea ecosystem is now a matter of serious concern [147].

In terms of the degree of disturbance of their ecosystems, the Caspian and Azov Seas fall between the Black Sea and the Aral Sea. Before the 1980s, fluctuations in the level of the Caspian Sea, the intensification of the circulation processes in the water column of its deep water areas, and a decrease in the input of biogenic substances with river water caused a decrease in biological productivity at all levels, and the deterioration of the fishes' food base (especially in the north Caspian). However, observed changes in the processes of biological production cannot be considered irreversible. It can be assumed that human-induced disturbances in the Azov Sea ecosystem have not become disastrous. To a certain extent they can probably be compensated for under conditions of favourable spatial and temporal variability in the hydrophysical and hydrochemical regime of the sea. At the same time, the appreciable water level rise in the Caspian Sea and the decrease in the Azov Sea's water salinity, observed over the past few years, which were caused by an increase in the natural rate of streamflow, probably did not bring about the restoration of the historically established ecosystems of these water bodies. For example, the opinion that it is only the water level of the Caspian Sea that has returned to the "norm" is being aggressively advocated.

We should bear in mind the uncontrollable export of poisonous substances from agricultural fields, especially from rice check-plots, to say nothing of the traditional set of industrial and domestic wastes. Information about the latter has just begun to find its way into reference books and scientific papers, and into the mass media. We now know a lot about the ecological catastrophe in the Aral Sea region. The consequences of a similar event, were it to occur in the Azov Sea basin, would be no less disastrous for the one reason that, whereas tens of thousands of people inhabit the Aral Sea coast, the population of the Azov Sea coastal zone is of the order of tens of millions.

On the whole, the degradation of the conditions of the southern seas continues, with minor fluctuations. Probably, the general industrial decay in the former USSR is exercising a certain positive effect. The increase in the natural rate of streamflow (or decrease in the withdrawal of river water for economic consumption) cannot guarantee the restoration of the biological productivity and recreational potential of the southern seas. Such a problem can only be solved under the conditions of a significant reduction in the input of pollutants into these water bodies.

Today it is no use looking for who to blame for what has happened in the southern seas. Who will dare to argue seriously against the necessity for constructing dams, developing irrigational farming and applying fertilizers to agricultural fields? It is hardly possible to stop the process of river runoff regulation. Can we be sure that in the near future the scale of sea water pollution will be decreased due to more efficient application, careful storage and transportation of fertilizers, and that water treatment processes will be improved? We can hardly expect to get positive answers to these questions quickly. Nevertheless, it is time to proceed from passive statement to active implementation of nature conservation measures in the Aral, Caspian, Azov and Black Sea basins. The success of such measures largely, if not totally, depends on the degree to which they are scientifically substantiated.

However, at present the quantity and quality of available observation data restrict the use of modern methods (in particular, mathematical modelling) for the estimation and prediction of water bodies' response to intensifying anthropogenic stress. The available observation data, especially for sea water pollution, cannot ensure the solution of this problem. All this must be taken into account when planning research activities in the southern sea regions, organizing monitoring and especially in making scientifically substantiated recommendations for the mitigation of negative consequences, for the seas themselves and for their coastal areas.

It goes without saying that any impact on the life of the seas should be based not only on our knowledge of their ecological regimes, but also on comprehension of the mechanisms that maintain the balanced state of such complicated dynamic systems. Information on the Black Sea, accumulated for almost 100 years, has appeared to give us the right to produce and utilize its resources (fish, recreation, minerals, etc.). The result has turned out to be deplorable.

Finally, we would like to emphasize two things. First, the spatial and temporal locations of the observation network should provide the maximum possible amount of information on the marine ecosystem under review. And, second, the selection of methods, instruments and test objects should be properly substantiated in accordance with the objectives of the research to be carried out.

Thus, the problem of monitoring the marine environment and the ecosystems inhabiting it is one of the key problems of contemporary marine ecologonomics.

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CONCLUSION

In this book we made an attempt to analyze and substantiate the appearance and development of a new ecological–economic direction in the science of marine natural resources management — marine ecologonomics — which is based on the synthesis of results of ecological and economic studies of the World Ocean.

Within the framework of the ecologonomic approach, we have analyzed possibilities and means of regulating interactions between economic and natural marine complexes. The most important element of this approach is specifying the subject of investigation, within which economy and marine environment closely interact. This subject is ecologonomic systems, or systems of the type "ecosystem–marine environment–economy". From the viewpoint of management of such systems, it is relevant to determine the expense of compensation for damage, caused to the marine environment by human-induced contamination and the withdrawal of certain components of marine ecosystems, as well as the expense of prevention of such damage, and improvement of marine environment quality on the whole.

Even today we do not have adequate knowledge about processes which take place in the ocean to substantiate changes occurring in its components. At the same time, many countries possess high economic potential and powerful technologies, allowing them to radically change all of the aforesaid processes — both their quantitative parameters and direction.

In this connection, we should not underestimate the global environmental danger of uncontrolled and unsubstantiated human activity in the ocean. Difficulties in projecting the management of marine natural resources, as well as difficulties in planning environmentally-minded economic development of coastal areas can be explained as follows:

(1) The rate and scale of human-induced changes in the ocean are very high and largely exceed those of oceanologic, economic and ecological investigations. As a result of insufficient scope and the uncoordinated character of research activities, aimed at studying basic physicochemical and biological processes in the ocean, the present-day science can only suggest a few recommendations concerning optimization of production, use, reproduction and conservation of marine natural resources;

(2) There are nearly 100 coastal countries, exercising economic activity in the ocean, the concepts and principles of environmental policies of these countries differ enormously. The prevailing principle of environmental policy of most coastal countries is to not burden their national budgets with expenses for marine environment protection. Unfortunately, Russia is not an exception;

(3) The water area of the World Ocean is still an area not so much for international cooperation, as for economic competition, which hampers rational management of the World Ocean natural resources.

Problems, arising from a process of elaboration and scientific substantiation of measures on marine environment conservation and marine natural resources management are solved within the framework of traditionally adopted methodological approaches. It has now become possible to suggest a general methodological concept of ecology and economics, which will serve as the basis for practical realization of the aforesaid measures.

Within this concept, any process pertaining to the World Ocean resources management is considered as substance and energy exchange between "ecosystem" and "economy" within the "marine environment".

The scheme of system-forming relations between ecology and economy can be presented as follows. Environmental requirements form a set of restrictions, specifying the maximum possible load value on the marine environment, within which the marine economy can operate. These restrictions, in their turn, should ensure normal functioning of marine ecosystems, inhabiting this environment.

We suggested investigating ecologonomic systems according to four main directions.

The first direction is the analysis of a complicated hierarchical set of processes, occurring in ecologonomic systems. Within the framework of this direction, the character, forms and scale of present and past interactions in the system of the type "ecosystem–marine environment–economy" are determined. Here it is relevant to theoretically substantiate and outline ways of solving the problem of stability of the ecologonomic system in line with the concept of the balanced state of marine ecosystems.

The second direction is the elaboration of theoretical fundamentals of ecologonomic systems management. Within the framework of this direction, based on the knowledge of objective laws of ecologonomic systems development and the value of maximum possible anthropogenic load on them, we should work out general methodological principles and specific techniques of management. In this case, it is also important to elaborate environmental and economic criteria of such management, as well calculate and express, in money terms, the value of damage that is caused (or can be caused) to the ecosystems under consideration.

The third direction is the evaluation of marine natural resources and properties of the marine environment. Whilst carrying out investigations in this direction, we must not confine ourselves to economic evaluations alone, but try to elaborate a whole set of estimation criteria and reference units with due account of environmental requirements.

The fourth direction is the mathematical one, envisaging mathematical modelling of ecologonomic systems.

The unity of ecology and economy allows for the control of both direct dependencies and "feedbacks" in the systems of the type "ecology–marine environment–economy", based on the knowledge of natural and economic development laws. The unity in question is based on the main category — marine environment quality — which is a comprehensive characteristic of dynamic properties of both the marine environment itself and ecosystems functioning within it.

In this work, for the first time in scientific literature, ecologonomic principles of marine natural resources management were elaborated and a wholesome concept of marine natural resources production, use, reproduction and conservation was put forward.

Natural resources management should be systematic, taking into account depletability of individual types of these resources. For this reason, the book presents economic substantiation of marine ecosystem resources conservation and reproduction, based on a set of estimated and predicted parameters of the analyzed ecosystems and human-induced changes in the aforesaid parameters.

Analysis of ecologonomic systems, presented in this book, allows us to regulate the processes of management of natural resources within individual water areas of the World Ocean and development of shelf areas, that has already started. This is very important because in the future marine natural resources will be produced from greater depths, and resources production processes will envelop ever increasing areas. At present, large-scale economic development of sea water areas is restricted by available financial resources: capital investments required per unit resource produced increases with the depth and area, enveloped by the production process.

Anthropogenic contamination of the World Ocean is in progress. Recently, the scale and degree of contamination of inland seas and deep bays has increased appreciably. Pollution fields are formed mainly in coastal waters in the vicinity of large industrial and/or agricultural enterprises, big cities and river mouths, and in the open sea — along marine traffic ways and in places of oil production from the sea bottom. The Sea of Japan, the Baltic, Northern and Irish seas, and certain regions of the Mediterranean Sea are considered to be the most heavily contaminated. The Gulf Stream waters bring pollutants from the coast of the American continent to Europe, where they accumulate. As a result, the seas, which were very clean in the past, are becoming heavily polluted.

Special attention is therefore paid in this book to the economic evaluation of ecological consequences of marine environment contamination at the ecosystems level, which also contributes to the scientific novelty of this work, because up until now, economic evaluations at the ecosystems level have not been carried out. As a result, it has become possible to develop a totally new approach to economic and ecological evaluation of marine environment conservation measures.

It is worthwhile mentioning one of the most important functions of the World Ocean – that of a gigantic filter, purifying water in a process of atmospheric moisture circulation. The ocean receives polluted river and rain waters, which evaporate from the vast ocean surface and then returned to the land as clean atmospheric precipitation, falling onto its surface.

Although at present the ocean can cope with its function of a "global filter", in the future, as a result of progressive contamination of sea water, such a task may be "beyond its powers".

As mentioned earlier, sea currents carry pollutants far away from the place of their discharge. The problem of marine environment contamination has thus acquired a global character, and its solution necessitates the joining of efforts of all the coastal countries and numerous international organizations, which have already been set up and under the aegis of which numerous bilateral and international programs and projects are being developed and realized, and special conferences, symposia and workshops are being organized. Among such organizations we can name the International Geographical Union, as well as a newly-set European Coastal Association for Science and Technology (EUROCOAST).

Within the framework of largest international programs, such as the International Geosphere–Biosphere Program, Global Change, Human Dimensions Program, etc., such an acute and complicated problem as distinguishing of the anthropogenic component of global environmental changes will be solved.

The growth of the Earth's population, resulting in an increased demand on natural resources of the World Ocean will increase the probability of economic and environmental conflicts in coastal regions, caused mainly by the incompatibility of certain types of human economic activities within them. In this respect, marine environment conservation will soon become the key element in marine policy of different countries. Several documents have been adopted, dealing with the management and control of marine environment conditions, marine ecosystem resources production, use, reproduction and conservation (e.g. special directives of the European Council, several international conventions on marine environment contamination, international agreements, laws or legislative acts of many coastal countries, such as the Netherlands, France, Spain, the USA, Portugal, Italy, Brazil, China, Turkey, Norway, Denmark, Canada, India, and some others). For example, in Brazil, the basic principles of National Policy in the domain of marine environment conservation and marine natural resources management are included in the Constitution of the country.

It is not by chance that in this book, new recommendations on the improvement of economic mechanisms of marine natural resources management and the increasing of its efficiency have been developed within the framework of the ecologonomic approach.

Up until now, in many countries, marine natural resources production was regarded as incompatible with their conservation. However, today, most of the countries try to adhere to the principle of balanced economic development, taking into account environmental requirements. This is the basis for distinguishing ecologonomic systems according to a certain combination of environmental and economic categories and criteria. In the process of distinguishing such systems, an increasingly greater part is assigned not only to economic criteria of natural resources management, but to the preservation of marine environment quality as well. It is emphasized that human impact should not deprive the marine environment of its self-regulation and adaptation capacity, but improve it where possible, attributing to it new properties which can be useful for man and not destroy the self-restoration capacity of marine ecosystems.

We would like to remind the reader once again that before exercising any impact on any natural process, it necessary to carry out special investigations, in order to select optimum ways of natural resources management in order to minimize the cost of such management and decrease the degree of disturbance of natural processes. The principles and methods of estimating anthropogenic changes, which are elaborated on the basis of their long-term observations, should be used for developing various models, revealing mechanisms of stability and self-restoration of the marine environment.

Control over the state of marine ecosystems, particularly in coastal areas, should be based on criteria allowing for easy and quick determination of economic damage caused by anthropogenic impact on the marine ecosystems, and also accounting for all the processes that occur in the investigated regions or sea basins. Therefore, while unifying requirements to anthropogenic loads, special attention should be paid to determining not only the maximum permissible concentration of pollutants, but the ecologically permissible load on marine ecosystems as well.

It goes without saying that marine environment control requires setting up an effective monitoring system.

The system of monitoring, suggested by us, involves observations (both temporary and permanent, carried out in the given points of an individual sea basin) and control over the state of marine ecosystems. The observation data, in their turn, serve the basis for predicting variations in the state of marine ecosystems.

It is not always the case that the economic effect of marine environment conservation can be measured directly. The economic efficiency of any production process, involving the use of marine natural resources as raw materials for finished products, is a time-dependent parameter: negative economic consequences can remain implicit for a long time and manifest themselves much later, when the positive economic effects of production and utilization of certain types of marine resources have already "expired". In such a case, the negative effect can bring the positive one to zero, and even exceed it. Neutralization of these negative environmental consequences will require tremendous efforts and financial expense.

The logical and indispensable completion of the elaboration of theoretical fundamentals of marine ecologonomics, in particular, land and sea water area regionalization of the World Ocean, should be practical verification of theoretical results obtained by means of substantiating concrete scenarios of economic development in the regions — belonging both to one country and to several neighbouring ones. Economic development projects for such "international" ecologonomic regions are important primarily for international organizations dealing with environment protection, e.g. the United Nations Environmental Program (UNEP), the Scientific Committee for Environmental Problems (SCOPE), and some others. A concept of ecologonomic regionalization, suggested in this book, will promote the development of mutually beneficial scientific, technological, and economic cooperation in the solution of problems of marine natural resources production, use, reproduction, and conservation.

Intensification of human economic activity in the World Ocean and coastal areas results in increased anthropogenic load on marine and coastal ecosystems. In this connection, in addition to calculating the damage caused to the marine environment as a result of its contamination and the withdrawal of certain components of ecosystems for use as raw materials in the production process, and estimating the efficiency of nature conservation measures, it will be necessary to prepare special cadastres of marine natural resources for every individual region. However, this is a separate problem, whose solution may necessitate writing another book as big as this one.

Finally, we would like to say a few words about the role of mathematics in ecologonomics. Mathematics provides the instrument for processing observation data, as well as the language for describing the processing of results. By creating its own body of mathematics for modelling, this new science adapts it for the solution of practical problems — prediction of marine environment state and its future stability under assumed values of anthropogenic impact.

In our opinion, mathematical modelling of ecologonomic systems is one of the most perspective research directions, both in ecology and economics independently, and in ecologonomics — a new science emerging at the junction of these two sciences. Mathematical modelling allows us to reveal the components of real processes and systems, which cannot be singled out and abstracted in a real marine environment.

Among the most wide-spread mathematical models, two classes can be distinguished: analytical (explaining reasons for various processes) and descriptive (used mainly in forecasting). Descriptive models are also sometimes called "empiric".

Analytical models are very well substantiated theoretically and make use of assumed or existing regularities of different processes. They seem attractive to us, because they are universal for a given class of investigated phenomena. The main instruments of analytical modelling are mathematical physics, theory of optimum management, functional analysis, etc. In fact, the "language" of analytical models is differential or algebraic equations. At present, these models are used to study physicochemical processes (vertical water circulation, pollutant migration and transformation, and so on), as well as certain marine ecosystems (e.g. "phytoplankton–zooplankton") and some biological communities (e.g. with "predator–victim" relations).

Among *descriptive models*, which have recently become very popular, we can single out the model of the Aral Sea ecosystem, the Baltic Sea model (developed at the Stockholm University), and various simulation models (e.g. the ones predicting the expansion and transformation of biological communities). These models allow us to develop various forecasts, mainly short-term ones. Unlike analytical models, descriptive ones provide quick and effective feedback with the simulated object and, therefore, can be adapted to new input data or improved, where the volume of input data increases or becomes more detailed and precise. Almost all of these models allow for computer realization. However, their disadvantage is that they do not facilitate the understanding of concealed mechanisms of the investigated processes and phenomena.

Expert estimations are becoming ever more important at present, as more and more attempts are made to develop alternative variants of the behaviour of global ecosystems, of which the World Ocean is one.

Semiotic models are developed at the "juncture" of descriptive and analytical ones. These models, unlike numeric ones, operate with symbols and symbolic systems of complicated structure. Semiotic models operate in a dialogue regime between the man and computer. They can be used to elaborate different variants of ecosystems' behaviour. It is especially important that analytical models, developed earlier, can be included in semiotic models as elementary symbols. Another difference between the models under review is that, whilst only qualitative methods are used in analytical and descriptive models, both qualitative and quantitative techniques of analysis and description are applied in semiotic models.

The development of semiotic models requires new methods of processing information of a qualitative character. Almost all the available techniques of formal methods and logics turn out to be useless for modelling at the semiotic level, since they require closeness within the framework of adopted calculation and abstraction from the reality. In fact, a new theoretical basis for such modelling is now being laid, which stimulates the development of non-traditional mathematical procedures.

The forecast of the state of an ecologonomic system (including its modelling) is relevant for the control over marine environment quality. This book, being mostly of a theoretical character, can nevertheless be useful in solving certain practical problems pertaining to the marine environment.

Many theoretical and methodological prepositions of the book have already been used by us in our practical work on marine environment conservation and marine natural resources reproduction, while elaborating regional development programs at the request of local administrative bodies of several regions of the Russian Far East. In our opinion, the problem of elaborating a unique strategy of natural resources management, not only for individual regions, but for the whole World Ocean has already become acute.

Finally, we hope that this book itself will be helpful in teaching economic theory of natural resources management to students and post-graduates.

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