Tangible outline of the whole elephant

(Results of ecosystem studies of biological resources in the far-eastern seas in 1990s)

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Dr. Vladimir Radchenko is the Deputy Director of TINRO-Center (Pacific Scientific Research Fisheries Center, Vladivostok, Russia). His interests include fish community dynamics in the northwest Pacific Ocean, carrying capacity and climate change issues, and the ecology of Pacific salmon during their sea life. In 1994, Vladimir received a Ph.D in Marine Biology for his thesis entitled "Composition, structure and dynamics of nekton communities of the Bering Sea epipelagic layer". He also works on problems of rational exploitation of living resources, fisheries management, and conservation in far-eastern seas. Vladimir is involved in various PICES activities as a REX Task Team co-chairman, member of the Biological Oceanography Committee and the Executive Committee for the CCCC Implementation Panel, and was formerly a member of WG5 on the Bering Sea and the Fishery Science Committee.

The major result of large marine ecosystem studies conducted by TINRO-Center in the Russian Far East has been the development of “the big picture” of long-term dynamics of the main components of the ecosystem. Tracing the path of these developments inspired the title of this article about several blind people describing an elephant’s appearance. In our case, the general outline of the structure and function are beginning to show through the darkness of uncertainty. The individual elements of the whole picture were revealed through key research directions that included:

- studies of long term variability in the ecosystems;
- quantitative abundance estimation of biological resources, calculations of fish productivity and total biological productivity levels, clarification of trends of their dynamics;
- structure of pelagic and bottom communities, dynamics of biodiversity parameters;
- carrying capacity of far-eastern seas (Shuntov, 1999).

Thirty-four expeditions were conducted during the 1990s (Fig. 1), and about 50 over the last 20 years. By adopting some of the practices developed during expeditions of the Russian Academy of Science, methodological improvements were made, but significantly supplemented by our studies of higher trophic levels, especially the ecology of commercial fishes and invertebrate species. New methods were developed to rapidly process oceanographic data, especially for plankton ecology and the feeding habits of nektonic fish and invertebrates. This allowed primary conclusions to be reached before the end of an expedition. Therefore, the results were immediately available to develop recommendations for the management and conservation of fisheries resources.

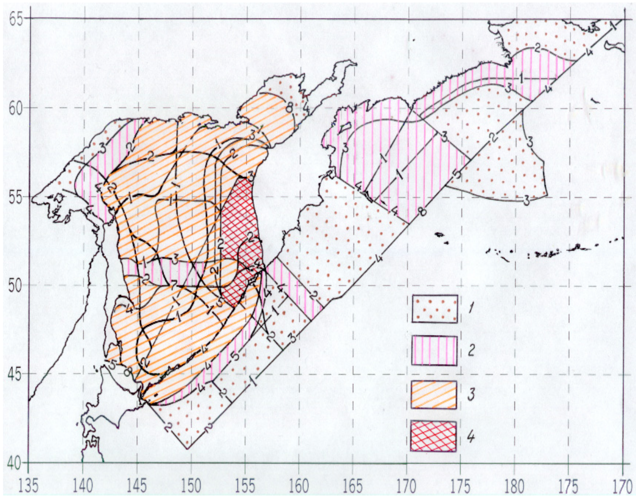

Fig. 1 Survey area for TINRO-Center biological resources ecosystem studies, 1990 - 2000. 1 – by 1-5 cruises; 2 – 6-10 cruises; 3 – 11-20 cruises; 4 – more than 20 cruises. Isolines indicate the survey borders and number of surveys conducted in these borders.

The ecosystem approach assumes synchronous collection, processing and analysis of material on all species inhabiting a study area. Conclusions about stock conditions of harvested species are made based not only on their abundance, which can be inexact due to imperfection and inconstancy of methods, but also on processes occurring in the fish and planktonic communities, in

Table 1. Dynamics of some parameters indicating a decrease of water exchange between the far-eastern seas and Pacific Ocean in 1990s.

	1989	1990	1991	1992	1993	1994	1995	1996	1998	1999
Kamchatka Current outflow (0-1000m) through Kamchatka Strait	7.0	-	3.7	4.7	3.6	-	-	3.3	1.0	3.9
Average velocity of the W. Kamchatka Current at the sea surface layer (cm/s)	-	-	8.0	5.0	-	2.7	3.6	4.6	-	-

populations of ecologically related species, and environmental conditions. As had been forecast 10 years earlier by the Applied Biocenology Laboratory, two strong year-classes of herring appeared in the Okhotsk Sea in the mid-1990s (Shuntov, 1986). The prediction was based on an understanding of periodic fluctuations of pelagic fish stocks and was further supported by an hypothesis of expected cooling in far-eastern seas after the relatively warm 1980s. Marine surveys, analyses of collected data, and discussion in the scientific literature convinced the State Committee on Fisheries of Russia to increase the total allowable catch (TAC) of the Okhotsk herring threefold in 1995 (Fig. 2).

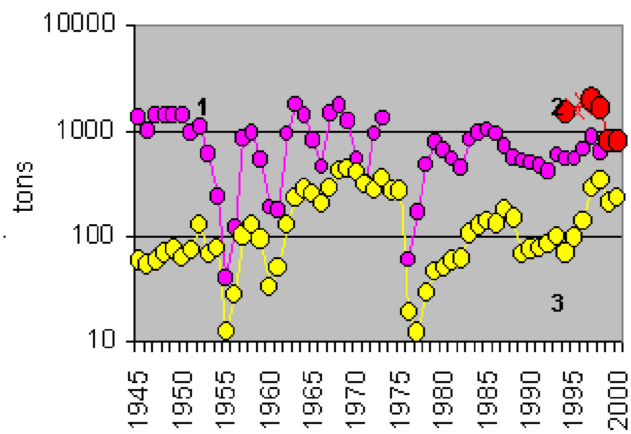

Fig. 2 Spawning stock fluctuations and catch dynamics of the Okhotsk herring population, 1945-2000. 1 - spawning stock estimations from the TINRO-Center, Magadan Division; 2 - corrections made by the TINRO-Center based on pelagic trawl survey data (crosses present an assumed level for years between autumnal integrated surveys); 3 - total annual catch.

The principles of planning and conducting integrated marine expeditions became customary after 1998 and these expeditions are now conducted in close cooperation with specialists of regional research institutes and laboratories of resource and ecological divisions. Resource studies, particularly at KamchatNIRO and SakhNIRO, have become imbued with an ecosystem focus. Research efforts of the TINRO-Center and other regional research institutes have been joined by programs of integrated studies of biological resources in the Bering, Okhotsk, and Japan Seas for 1998-2002.

Exchanging ideas with scientists conducting similar studies in different regions of the World Ocean (mostly through scientific publications) is the driving force of the far-eastern seas ecosystem studies. Some fragments of information and ideas were found in papers by many foreign authors, dealing with adjacent ocean areas. These pieces were assembled with our own new findings as parts of a giant mosaic. For example, Okada's (1986) discovery of the walleye pollock migration route in the Aleutian Basin of the central Bering Sea allowed us to conduct a more directed search for the continuation of the route in the Commander Basin within the limits of the Russian EEZ (in those times, Soviet EEZ). Hollowed and Wooster (1992) provided an explanation of the cause of decreasing water exchange between the Bering Sea and the Pacific Ocean, and the inter-annual variability of ocean current patterns and water structure observed since the early 1990s.

Hypotheses on long-term variability in the physical components of the far-eastern seas ecosystem have become organized in an harmonious scheme by combining all processes and phenomena occurring in different regions of the North Pacific. The long-term dynamics of atmospheric activity centers over the ocean lead to large-scale changes in the pressure field structure, with interdecadal periodicity. A decreasing advection of oceanic waters into the far-eastern seas (Table 1) is the consequence of an increase in water circulation intensity in the Subtropical Gyre (with the strengthening of the California Current), and a decrease in the Subarctic Gyre (with the weakening of the Alaska Stream along the North America coast). This phenomenon was accompanied by a northward shift of the main fronts and currents in the northern hemisphere.

The temperature of waters circulating in the Subarctic Gyre decreases as these waters receive less solar radiation after their northward shift. Cooling of shelf waters is more intensive in the far-eastern seas due to atmospheric variability. Beginning in the late 1990s, the seasonal development of atmospheric processes over the northwestern North Pacific is similar to that of the "cold decades" of 1960s – 1970s. The number of days with a zonal mode of atmospheric circulation pattern decreased. It is known that cold Arctic air masses shift into the Bering and northern Okhotsk Seas during periods of low atmospheric circulation zonal index. It leads to a drop of air temperature and subsequent surface water cooling.

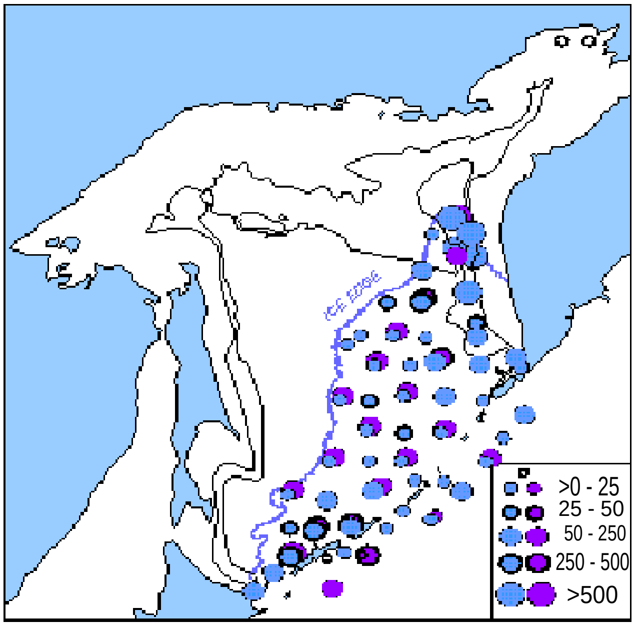

Fig. 3 Example of mesopelagic fishes catch distribution (kg per hour of trawling) in the middle (200-500 m. blue circles) and lower (500-1000 m, violet circles) pelagic layers in the Sea of Okhotsk, March – April of 1990.

Increasing temperature and salinity gradients in the border layers separate water masses, both vertically and horizontally. Continuing frontogenesis makes preconditions for water transport acceleration along fronts, and for water mass interaction through frontal zones. Therefore, some preconditions for the next climate-oceanological regime shift are beginning to appear in the far-eastern sea ecosystems.

Considerable clarification was made concerning current and potential levels of biological and fish production of the far-eastern seas. Firstly, a theoretical consideration was made because there was insufficient data on biomass (or production) at all trophic levels through most regions of the far-eastern marine basin prior to the ecosystem studies. The calculations showed that the abundance of commercial species was potentially substantially higher in the Russian far-eastern seas than previously thought.

This was the preamble of the practical findings that followed in the marine expeditions. Estimates of walleye pollock biomass showed that >45 million t of walleye pollock inhabited far-eastern seas and adjacent Pacific waters at the highest level of abundance. Thereafter, re-estimations of stock conditions and recommendations to expand fishery exploitation ensued for the Okhotsk and Korf-Karaginsky herring populations, cod, saffron cod, and the schoolmaster squid. Data summarizing the ecology, assessment of biomass and role of mesopelagic fishes in pelagic ecosystems became a special and important part of ecosystem studies. It was found that these fishes are relatively uniformly distributed in mesopelagic layers (Fig. 3), and are practically inexhaustible (Table 2) with current fisheries techniques. They undoubtedly represent significant reserve of protein for future food and technical products.

After 1990, the numbers of relatively thermophilic species, walleye pollock or Japanese sardine, noticeably decreased. In contrast, the fish species that increased preferred a relatively lower water temperature. Three major stocks of Pacific herring (the Okhotsk, the Gizhigino-Kamchatsky, and the Korf-Karaginsky populations) increased in biomass from the late 1980s to the early 1990s. From the south, the Japanese anchovy expanded their range northwards, up to the Ayano-Shantarsky region of the Okhotsk Sea (Fig. 4). Studies conducted during the late 1980s showed an interesting feature: walleye pollock declined in abundance when herring stocks increased, and vice versa. The 1980s was a "pollock epoch", and a "herring epoch" was forecast for the 1990s. What actually happened in the 1990s was a trend of declining pollock abundance and the growth of herring stocks in the northern Okhotsk Sea. The herring proportion in the pelagic fish community increased noticeably (Table 3). If we consider the dominance of the 40–60 year cycle in the variability of biological structure and physical surrounding of pelagic ecosystems, and disengage ourselves from variability of lower frequency, we can conclude that pollock stocks will reach a minimal level not earlier than the second decade of the 21st century.

Table 2. Mesopelagic fish biomasses (thousand metric tons) estimated for the middle (200-500 m) and lower (500-1000 m) pelagic layer basing from trawl survey data, March – June of 1990.

	Bering Sea		Okhotsk Sea	
	200 – 500 m	500 – 1000 m	200 – 500 m	500 – 1000 m
Light-rayed lampfish	2737.6	3752.3	57.6	42.9
Dark-rayed lampfish	14.0	1382.7	38.6	1025.0
Other myctophids	55.0	52.2	9.4	77.5
Northern smoothtongue	42.4	237.4	1477.7	2167.7
Eared blacksmelt	34.5	164.6	349.7	1434.4
Other bathylagids	22.3	650.1	0.3	632.4
Pacific viperfish	45.3	203.0	2.0	83.5

Table 3. Biomass (thousand metric tonnes) and ratio of species in pelagic fish community in the northern Okhotsk Sea in late summer – autumn of 1988, 1997-1999.

Species	1988		1997		1998		1999	
	Biomass	%	Biomass	%	Biomass	%	Biomass	%
Pollock	9475.2	94.2	4391.9	57.0	3636.5	51.5	1278.0	17.4
Herring	497.2	4.9	2492.9	32.3	1209.7	17.1	1877.6	25.5
Capelin	11.3	0.1	31.0	0.4	1002.7	14.2	929.3	12.6
Sandlance	7.8	0.1	30.3	0.4	21.2	0.3	1.5	+
Lumpfishes	20.8	0.2	37.1	0.5	127.1	1.8	41.2	0.6
Others	46.9	0.5	727.7	9.4	1064.0	15.1	3223.9	43.9
Total	10059.2	100%	7710.9	100%	7061.2	100%	7351.5	100%

Maintenance of the steady functioning of individual species and ecosystems is ensured by the complex mechanisms that regulate abundance and population density of marine species. These mechanisms regulate both reproduction and survival according to life history strategies. It has been found that cannibalism in walleye pollock and schoolmaster squid increases during shortages of forage zooplankton, both seasonally and inter-annually, especially in winter and in years of strong year-classes. Cannibalism in the schoolmaster squid is estimated to be 0.9 million t annually. This mechanism sustains the spawning stocks during unfavorable seasons, and regulates total abundance. Despite a declining abundance of pollock, cod, and Greenland turbot (all significant predators of squid), the squid biomass did not increase noticeably in the Bering Sea. It can be related to an increase in cannibalism among squid and the conditions of squid reproduction.

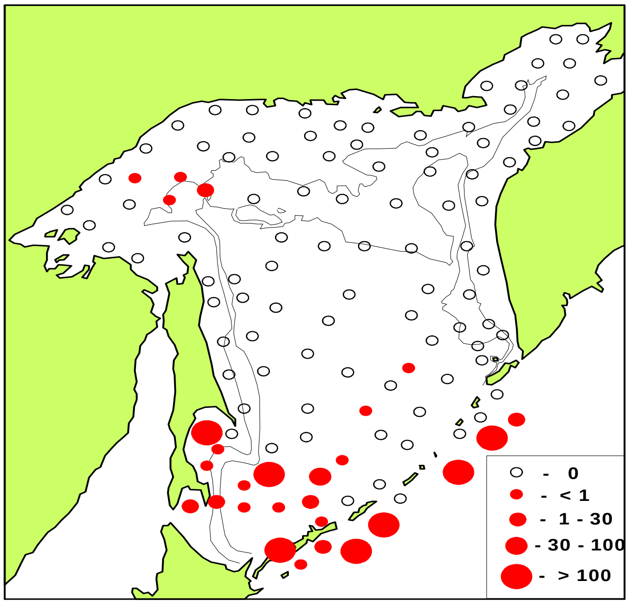

Fig. 4 Catch distribution (thousand fish per square km) of Japanese anchovy in summer-autumn of 1998.

There are consistent processes involved in the overall ecosystem functioning, like those in separate populations of sea animals. The ratio of biological productivity to total volume of consumed organic matter inside the system is also regulated by similar mechanisms. Substantial decreases in pelagic nekton biomass are considered to be one of the major features of ecosystem reconstruction in North Pacific during the climate–oceanologic regime shift of the early 1990s. Correspondingly, the predation by nekton on planktonic communities weakened and the following circumstances came about (Fig. 5). However, the last stage occurred at a lesser level than in the late 1980s in conditions of new epoch and distinctive structure of fish communities.

Despite the leaps in some fish species abundance, the structure of fish communities in the far eastern seas remains relatively stable. For the Bering Sea, although there has been a decrease of pelagic fish biomass by more than half, the planktivorous nekton (pollock, herring, schoolmaster squid) maintain a leading role in transporting biomass to the upper trophic level organisms (Fig. 6). This monthly flow is estimated at 103 thousand t (for the end of summer – beginning of autumn), whereas directly from lower trophic levels to the predator fish guilds – is estimated at 134 thousand t. In order to support this production, the planktivorous nekton consumes 2.25 million t of living substance (raw weight) monthly, including 373.5 thousand t of cannibalistic consumption by fish and squid (pollock, schoolmaster squid).

The interrelationships among ecosystem components and their integration level can be examined in the dynamics of biological diversity. Last year, the dynamics of species diversity (Shannon index), and species uniformity by abundance (Pielou evenness index) were studied in the Sea of Okhotsk nekton, macroplankton and macrobenthos. From 1985 to 1998, the variety of species in the pelagic fish community increased following an S-shaped curve up to the new quantitative level in the research area (Fig. 7). The Pielou and Shannon indices undulated to a relatively higher level. The analysis of separate ecological groups of organisms and areas showed similar attributes in both pelagic and bottom ecosystems. All changes spread from south to north. In the benthic zone, especially in deep-water areas, the process was slower than in the pelagic zone.

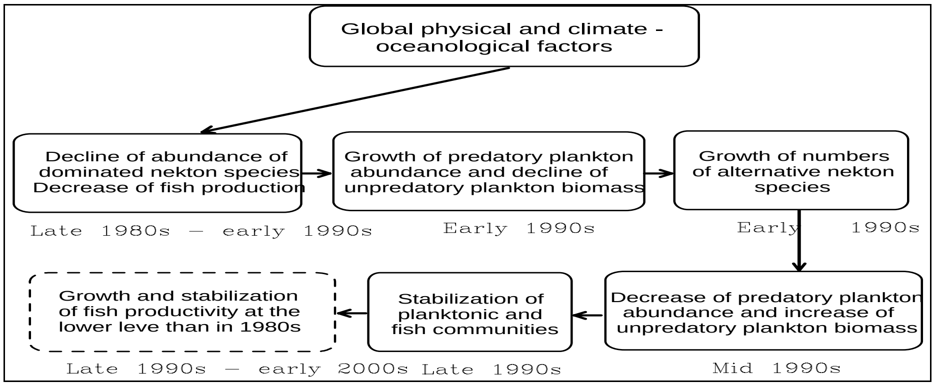

Fig. 5 Generalized ecosystem reorganization in the epipelagic layer of the far-eastern seas (after Shuntov et al., 1997).

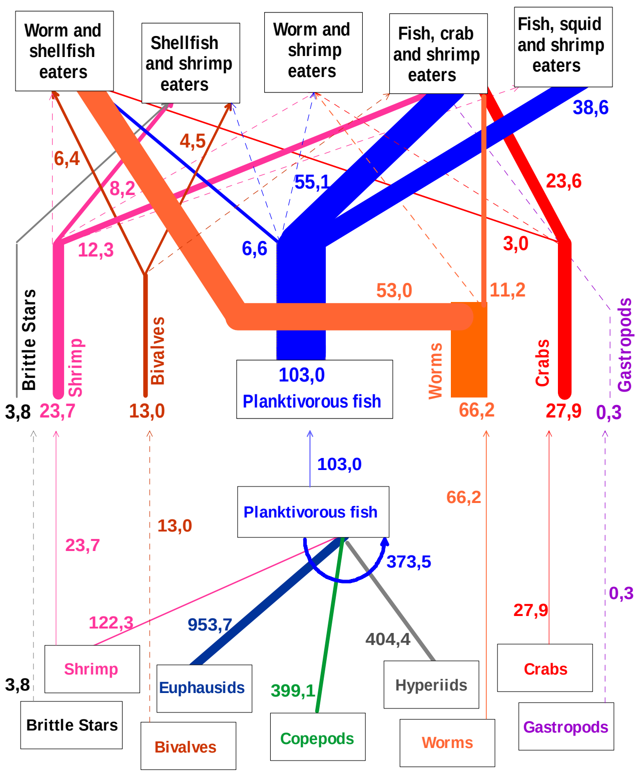

Fig. 6 Matter flows (1000 t per month) between the nekton guilds and lower trophic level organisms in the W. Bering Sea shelf and slope, 1998. Arrow' thickness reflects volume ratio of matter flows. In the upper panel, all arrows are 10 times thicker than in the lower panel. Matter flows with transport volume less than 20 (lower part of Figure) and 2 (upper part) thousand tons per month are indicated by dashed lines of equal thickness.

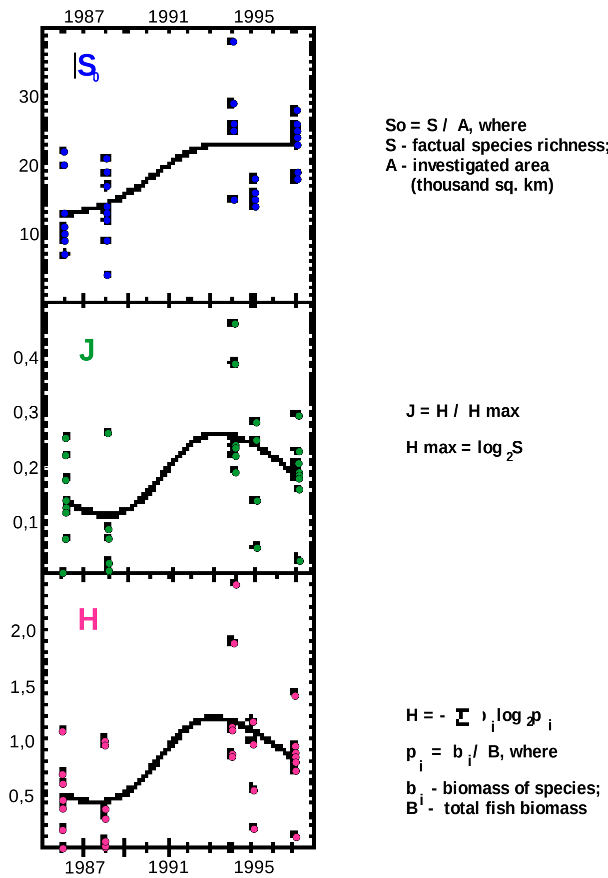

Fig. 7 Long-term trends of species richness (so), evenness (J), and diversity (H) of pelagic fish community in the northern Okhotsk Sea. Each point corresponds to one biostatistical area.

Understanding species diversity variability is needed in studies of multifaceted concepts of ecosystem "carrying capacity". The term "carrying capacity" is currently defined as the biomass of a species that can be maintained by the ecosystem resources and conditions. Obviously, the carrying capacity of a guild or a group of organisms is not equal to the sum of the component carrying capacities.

Determination of the ecosystem carrying capacity for separate guilds or ecological groups of organisms is a necessary stage for developing the management of commercial species resources within multi-species fisheries theory. Apparently, the ecosystem research of biological resources will be developed in this direction in the future.