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Opportunistic settlers and the problem of the ctenophore *Mnemiopsis leidyi* invasion in the Black Sea

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Notes

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Executive Summary

1 Eutrophication and a massive population explosion of *Mnemiopsis leidyi* in the Black Sea has led to tremendous changes in the Black Sea ecosystem and substantial economic losses. Taking into account the importance of the problem and scale of anthropogenic intervention into the Black Sea ecosystem, UNEP requested GESAMP to review the problem of opportunistic settlers and advise on a possible course of actions. This proposal was supported by the other sponsoring agencies of the Group. UNEP, IMO, FAO and Unesco-IOC undertook to contribute financially to this work.

2 GESAMP agreed that work should be carried out by a group of experts under the following terms of reference:

- to assess the occurrence, distribution, reproductive biology and physiological features of the intruder ctenophore, its ability to compete for food with pelagic fish, and control of its population by predators in its natural habitat;

- to assess the probable causes of the ctenophore outbreaks and their connection with other destabilizing factors and developments in the Black Sea Region;

- to assess the impact of the ctenophore on pelagic and benthic communities and its consequences for fisheries; and

- to develop a strategy, and to recommend measures, to overcome the ctenophore and similar invasions in other parts of the world, using the Black Sea region as an example.

3 Meetings were convened at the UNEP Regional Office for Europe in Geneva from 10 to 14 January, 1994, and from 20 to 24 March, 1995.

4 The following conclusions were adopted by GESAMP:

.1 the state of the Black Sea ecosystem cannot be restored to its condition before the 1940s for the following reasons:

.1 human activities have increased both within and around the Black Sea;

.2 agricultural and industrial activities have increased;

.3 the flow of rivers has been altered in volume and quality; and

.4 six exotic species already have had a significant impact (the crab *Rhithropanopeus harrisi*, the snail *Rapana thomasiana*, the clam *Mya arenaria*, the fish *Mugil soiuy*, the comb jelly *Mnemiopsis leidyi*, and the clam *Cunearca cornea*) on the ecology of the system.

.2 the goals of any project for the rehabilitation of the Black Sea should be directed at both the environmental and economic improvement of the region. It was recognized that these objectives may be in conflict in some cases. However, given the irreversibly altered ecosystem with which we are now confronted, this document's strategy for the reduction of *Mnemiopsis leidyi* populations will contribute to progress towards both goals.

.3 rehabilitation of pelagic fish stocks along with the reduction of *Mnemiopsis leidyi* populations will require their sustainable exploitation, as well as improvement of the Black and Azov Seas environments;

.4 biological control is the most practical method for controlling *Mnemiopsis* populations in the Black Sea region. The preferred strategies of biological control are:

.1 the management of fisheries so as to enhance populations of indigenous fish competing with or grazing on *Mnemiopsis*;

.2 the introduction of economically valuable, specific predators of *Mnemiopsis*, such as the fish *Gadus*, *Peprilus* or *Oncorhynchus*; and

.3 the introduction of a specific comb jelly predator, i.e., *Beroe* sp.

It is recommended that the three strategies be evaluated further and pursued simultaneously in each part of the Black Sea region experiencing *Mnemiopsis* outbreaks;

.5 improvements in co-ordination among institutions, national and international programmes in the areas of scientific research, monitoring activity and control measures are essential for optimizing the success of the recommended strategies;

.6 finding an approach to control populations of *Mnemiopsis leidyi* is very important for the restoration of the Black Sea Region. It is also an important example for other enclosed seas of the world with similar characteristics (e g., Caspian Sea, Adriatic Sea, Baltic Sea);

.7 international attempts should be made to reduce the risk of exportation of *Mnemiopsis* from the Black Sea Region and the importation of further accidental introductions;

.8 international co-operation is essential for solving this problem, and should remain a high priority of the appropriate United Nations agencies, the riparian states of the Black Sea Region, and the international community. Improved coordination between research, monitoring, and control activities in the Black Sea Region is essential;

.9 the formation of a permanent Working Group on The Control of Marine Pest Invasions is recommended through a global mechanism such as GESAMP. This group would advise and recommend strategies on the prevention and post-introduction research and control of introduced species, and would communicate with other international agencies;

.10 studies on *Mnemiopsis* must continue in respect of its seasonal dynamics, regions of distribution, conditions of reproduction and feeding, and its impact on ecosystems and fisheries (finfish and shellfish) in the Black Sea Region; and

.11 studies on mechanisms and possibilities of control must be undertaken immediately in order to find potential controlling species and/or develop other options.

Acknowledgements

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All working group members are warmly thanked for their individual and collective expert contributions and hard work at the two technical working meetings and intersessionally, without which this report would not have been possible. They were as follows: James T. Carlton, Richard Harbison, Ahmet Kideys, Asen Konsulov, Erkki Leppäkoski, Vladimir Mamaev, Simion Nicolaev, Ivan Serobaba, Yuri I. Sorokin (Co-Chairman), Michail E. Vinogradov, Stanislav Volovik, Peter G. Wells (Co-Chairman), Victor E. Zaika, Yuvenaly Zaitsev, Ivan Zrajevskij (Secretariat).

Drs. R. Harbison (USA) and M. Vinogradov (Russia) met between meetings, resolving complex technical issues and preparing substantial text for the report. Dr. J. Carlton (USA) also prepared text in advance of the two meetings. Dr. John Caddy of FAO, Rome, attended the first technical meeting and contributed substantially to the fisheries discussion and first draft report. GESAMP members in 1994 and 1995 reviewed and commented on the report, and gave its final approval.

The report was completed and edited by the Chair, Dr. P.G. Wells, of Environment Canada (Dartmouth, Nova Scotia), assisted by Dr. Yuri Sorokin, and by Dr. Manfred Nauke and Ms. Jennie Hallett of IMO, London. Any errors or omissions are the sole responsibility of the Chair and editor.

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1 Introduction

UNEP on the request of the governments of the region started development of the Action Plan for the Black Sea in 1991. The opportunity afforded by the Global Environmental Facility (GEF) was exercised. Jointly with the other two GEF partners, The World Bank and UNDP, a project "Environmental Management and Protection of the Black Sea" was developed and adopted for implementation. UNEP assisted Black Sea countries in the preparation and adoption of the "Ministerial Declaration on the Protection of the Black Sea". Both of these documents stress the need for protection of marine living resources and restoration and conservation of biodiversity in the Black Sea.

Eutrophication and a massive population explosion of *Mnemiopsis leidyi* in the Black Sea led to tremendous changes in the ecosystem and substantial economic losses. Taking into account the importance of the problem and scale of anthropogenic intervention into the Black Sea ecosystem, UNEP requested GESAMP to review the problem and advise on possible courses of action.

GESAMP agreed that work should be carried out by a small group of experts under the co-chairmanship Dr. Peter Wells and Mr. Yuri Sorokin, both members of GESAMP. Some GESAMP members expressed the view that the group should not restrict itself to the Black Sea ecosystem but should look at the problem from a global perspective. UNEP, IMO, FAO, and UNESCO-IOC agreed to co-sponsor the Working Group. Meetings were convened accordingly. The list of Working Group members is attached as Annex 1.

The terms of reference were the following:

- To describe the invasions of opportunistic settlers as an ubiquitous phenomenon in extant marine habitats, and to delineate the ecological aspects of the invasions, their cause, their impacts on ecosystems, and possible ways for their control.

- To assess the occurrence, distribution, reproductive biology and physiological features of the intruder ctenophore, its ability to compete for food with pelagic fish, and control of its population by predators in its natural habitat;

- To assess the probable causes of the ctenophore outbreaks and their connection with other destabilizing factors and developments in the Black Sea Region;

- To assess the impact of the ctenophore on pelagic and benthic communities and its consequence for fisheries; and

- To develop a strategy, and to recommend measures, to overcome the ctenophore and similar invasions in other parts of the world, using the Black Sea region as an example.

2 Distribution and Ecology of *Mnemiopsis leidyi*.

2.1 Setting the Black Sea Invasion of the Atlantic Ctenophore *Mnemiopsis leidyi* into a Global Context

2.1.1 Ubiquity of Invasions and Invasion Terminology

Invasions by exotic species into coastal zones and inland seas and lakes of the world have become exceedingly common in recent years due to many factors. These include changes in the donor ecosystem, changes in the transport vector, and changes in the recipient ecosystem (which are focused upon in this report).

Since the mid-1980s, ecologists have referred to introduced species (species transported and released through human activities) as biological invasions, regardless of the size of the populations or the ecological impact. This is because introductions have exhibited a full range of impacts and abundance (as discussed below), making it impossible to select any one point in the continuum from very rare to very abundant and refer to it as an "invasion". In an ecological-evolutionary sense, biological invasions also include the natural range of spontaneous expansion of species. Other common terms for introduced species are exotic, alien, imported, foreign, non-native, non-indigenous, acclimatized, and opportunistic settlers. All of these terms may have somewhat different meanings for different purposes.

The modern-day ubiquitous nature of invasions is reflected in a brief list of examples of species that recently have invaded coastal ecosystems around the world (Table 1). Many more species could be added. Most of these invasions have been linked to the discharge of ballast water and associated sediments from ocean-going vessels.

It is important to note that less than 10 percent of all invasions are reported in the formal scientific literature, and that there is often a delay of 5 to 10 years or more in the first reporting of an invasion. The lack or delay of such reports does not reflect the abundance or importance of an invasion. For example, the mangrove ecosystems in Trinidad have been subjected in the 1980s to a major invasion of an Indo-Pacific mussel (bivalve mollusc), which is displacing native mangrove oysters.

2.1.2 Ecological Patterns of Marine Invasions

Where Invasions Occur

Few generalities can be made about marine invasions, other than their current ubiquitous nature (Table 1). Invasions may occur in disturbed ecosystems, such as the Black Sea, the Baltic Sea and San Francisco Bay. Invasions may also occur in marine coastal systems which have not been directly or obviously perturbed by human activities, such as the highly diverse exposed fringing coral reefs of the Hawaiian Islands, or the low diversity open rocky shores in the Gulf of Maine (USA/Canada). More invasions occur in disturbed and/or low diversity marine ecosystems, but these sites are those that also interface with primary vectors such as ballast water.

Post-Invasion Abundance

A species may enter a system and remain rare to common, or it may enter a system and become extremely abundant within some period of time after the initial inoculation. Ecological, biological (physiological), chemical, physical, and other factors regulate the abundance of a new species. It is rare to be able to draw simple correlations between any one factor and the "success" or "failure" of a given species. Correlations that are made have even more rarely been examined experimentally to establish causation. The species listed in Table 1 reflect the full range of post-invasion abundances. Superimposed upon this range are two additional patterns. Pattern "A" is that an introduced species may become extraordinarily abundant in the early part of its invasion history, and then become less abundant in subsequent years. The reasons for this pattern are often speculative, but have been linked to an increasing "balance" between the invader and its food resources, and increasing predation upon the invader by native or other introduced species. Pattern "B" is that the introduced species itself may undergo natural fluctuations (ranging from "blooms" to being uncommon to rare) within its native range. Distinguishing between these two patterns, especially within the first decade of an invasion, may be very difficult.

Post-Invasion Niche Breadth

Introduced species may express aspects of their fundamental niche not expressed within their native range. For example, the introduced species may survive and/or reproduce within a wider range of environmental parameters than previously known. These broader expressions may be due to release from predators or competitors, to new food sources, to novel physical and chemical regimes, to fundamental climatic differences or to a combination of any of these or to other factors.

Post-Invasion Ecological Impact

The ecological impact that an invading species may have varies as widely as in the other patterns described above. Some species enter a new ecosystem and have little apparent effect; at the other extreme, an introduced species may have obvious, extensive consequences as a predator, competitor, and/or disturber. However, it is particularly important to note that for the majority of introduced species (including almost all of those in Table 1), there are no studies of their ecological impact, leading some workers to the mistaken conclusion that there have been no ecological impacts. There may or may not have been impacts of such introductions.

How the *Mnemiopsis* Invasion Corresponds with General Ecological Invasion Patterns

Among recent global invasions, *Mnemiopsis* is similar in terms of relative abundance to the invasion of the Eurasian zebra mussel, *Dreissena polymorpha*, in the Laurentian Great Lakes and the invasion of the Chinese clam, *Potamocorbula amurensis*, in San Francisco Bay. However, it is unique among global invasions of the past 15 years in the scale of its impact in the Black and Azov Seas upon natural finfish fisheries.

Table 1

EXAMPLES OF RECENT GLOBAL MARINE AND LAURENTIAN GREAT LAKES INVASIONS IN THE PAST FIFTEEN YEARS[1]

Period First Discovered	Species	Introduced to
1979 to 1983	American razor clam *Ensis directus*	Germany/Denmark
	Japan/China hydroid *Cladonema uchidai*	San Francisco Bay
	Atlantic mysid *Neomysis americana*	Argentina/Uruguay
	Japan cumacean *Nippoleucon hinumensis*	Oregon
	Asian copepod *Oithona davisae*	San Francisco Bay/Chile
	Chinese copepod *Limnoithona sinensis*	San Francisco Bay
	Japan mussel *Musculista senhousia*	New Zealand/Australia
	Ind[2] mysid *Rhopalophthalmus tattersallae*	Arabian Gulf
	IndoPac jellyfish *Phyllorhiza punctata*	Southern California
	Japan shipworm *Lyrodus takanoshimensis*	British Columbia
	Medit alga *Polysiphonia breviarticulata*	N. Carolina, Dominica
	American comb jelly *Mnemiopsis leidyi*	Black Sea
	Asian clam *Theora fragilis*	San Francisco Bay
	Amer seaslug *Doridella* obscura	Black Sea
	Japanese seabass *Lateolabrax japonicus*	Australia
	IndoPac waterflea *Pleopis schmackeri*	Brazil
	Japan copepod *Centropages abdominalis*	Chile
	Japanese copepod *Acartia omorii*	Chile
	Pac clam *Scapharca cornea*	Black Sea
	Indo-Pacific goby *Butis koilomatodon*	Nigeria/Cameroon
	American worm *Marenzelleria viridis*	Germany
	Indonesia shrimp *Exopalaemon styliferus*	Iraq/Kuwait
	European nudibranch *Tritonia plebeia*	Massachusetts
	European shore crab *Carcinus maenas*	South Africa
	Medit mussel *Mytilus galloprovincialis*	Hong Kong
1984 to 1988	Chinese worm *Teneridrilus mastix*	San Francisco Bay
	Eur waterflea *Bythotrephes cederstroemi*	Great Lakes
	Atlantic shrimp *Hippolyte zostericola*	Colombia (Caribbean)
	Tropical green alga *Caulerpa taxifolia*	Mediterranean
	American blenny *Hypsoblennius ionthas*	Hudson River
	Atlantic copepod *Centropages typicus*	Texas
	Indian seabream *Sparidentex hasta*	Australia
	European seasquirt *Ascidiella aspersa*	New England

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1 References: Bourdouresque *et al.*, 1994; Carlton, 1987, 1989, 1992a, 1992b; Carlton and Geller, 1993; Carlton *et al.*, 1990.

2 Abbreviations: Amer - American; Aust - Australian; Dino - dinoflagellate; Eur - European; Ind - Indian; IndoPac - Indo-Pacific; Medit - Mediterranean; Pac - Pacific; Phil - Philippine; SoAf - South Africa.

Period First Discovered	Species	Introduced to
	Asian clam *Potamocorbula amurensis*	San Francisco Bay
	Japanese seastar *Asterias amurensis*	Australia
	Asian copepod *Pseudodiaptomus marinus*	Southern California
	Japan red alga *Antithamnion nipponicum*	Long Island Sound
	SoAf/Aust worm *Desdemona ornata*	Mediterranean
	Asian shrimp *Salmoneus gracilipes*	Southern California
	Japan dino *Alexandrium catenella*	Australia
	European? dino *Alexandrium minutum*	Australia
	Japanese dino *Gymnodinium catenatum*	Australia
	So American mussel *Mytella charruana*	Florida
	Indo-Pacific crab *Charybdis helleri*	Colombia (Caribbean)
	Chinese copepod *Pseudodiaptomus forbesi*	Southern California
	Eur bryozoan *Membranipora membranacea*	Maine/New Hampshire
	European ruffe *Gymnocephalus cernuus*	Great Lakes
	Japanese goby *Rhinogobius brunneus*	Arabian Gulf
	Phil/Taiwan goby *Mugilogobius parvus*	Hawaii
	Japanese kelp *Undaria pinnatifida*	New Zealand
	Japanese crab *Hemigrapsus sanguineus*	New Jersey
	Eur zebra mussel *Dreissena polymorpha*	Great Lakes
	Japan red alga *Antithamnion nipponicum*	France (Mediterranean)
	Atlantic clam *Rangia cuneata*	Hudson River
	Japanese kelp *Undaria pinnatifida*	Australia
	Japanese brown alga *Sargassum muticum*	North Sea
1989	Eur zebra mussel *Dreissena bugensis*	Great Lakes
to	South American mussel *Perna perna*	Texas
1993	European shore crab *Carcinus maenas*	San Francisco Bay
	Asian copepod *Pseudodiaptomus inopinus*	Columbia River
	American comb jelly *Mnemiopsis leidyi*	Mediterranean Sea
	Black Sea goby *Proterorhinus marmoratus*	Great Lakes
	Medit goby *Neogobious melanostomus*	Great Lakes
	European oyster *Ostrea edulis*	Rhode Island
	South American *Vibrio cholerae* 01	Alabama
	Sarmatic hydroid *Maeotias inexspectata*	San Francisco Bay
	Sarmatic hydroid *Blackfordia virginica*	San Francisco Bay
	New Zealand seaslug *Philine auriformis*	San Francisco Bay
	Asian shrimp *Exopalaemon carinicauda*	San Francisco Bay
	Mysid, *Hemimysis anomala*	N. Baltic Sea

[Note: description of many invasions discovered since 1989 have not been published yet]

Mnemiopsis was first collected in the Black Sea in 1982 (Zaika and Sergeeva, 1990). By the summer and autumn of 1988, it had become abundant throughout the Black Sea, including its offshore regions, to biomass levels of approximately 1 kg m^{-2} (Table 2). It then became very abundant in the summer and fall of 1988 (> 1 kg/m^2) in the whole Black Sea, including the open regions (Vinogradov *et al.*, 1989). It reached densities as high as ever known in North America, until 1991-92, when its abundance declined. In 1994 it increased again in some regions. These fluctuations suggest that rather than reflecting a "simple" Pattern A invasion (above), *Mnemiopsis* is indeed a classic Pattern B species. It is predicted that the abundance of *Mnemiopsis* will vary widely in the future.

In many ways, *Mnemiopsis* fits classic models of successful invaders (Mooney and Drake, 1986; Drake *et al.*, 1989). *Mnemiopsis* is susceptible and amenable to transport, it is a species of broad reproductive and physiological capabilities, and it has invaded an environment, i.e., the Black Sea, vulnerable to invasions. *Mnemiopsis* is abundant in ports and harbours of the Americas and can be pumped (presumably as larvae or small juveniles) or gravitated (as adults as well) with ballast water into cargo ships. While sufficient zooplankton may be available to sustain *Mnemiopsis* in ballast water on a voyage lasting 20 or more days from the Americas to the Black Sea, food resources are not necessary, as *Mnemiopsis* can live for three or more weeks without food, reducing body size at the same time (Reeve *et al.*, 1989; R. Harbison, pers. comm., 1995). As a rapidly-reproducing, self-fertilizing simultaneous hermaphrodite (Barnes and Ruppert, 1994), it possesses an ideal reproductive strategy for a colonizing species. It is a generalized feeder (Nelson, 1925; Mountford, 1980; Tiskhon-Lukanina *et al.*, 1992), not linked to any specific or obligatory prey. *Mnemiopsis* occurs over a very broad range of inshore habitats, salinities, temperatures, and water quality conditions (Harbison and Volovik, 1994), an ideal match for the equally variable and highly disturbed Black Sea ecosystem. Finally, the disturbance regimes of the Black Sea, combined with its low biological diversity (Mordukhai-Boltovskoi, 1969; Svetovidov, 1964), have long made the Black Sea an environment susceptible to invasions by temperate and subtropical eurytopic animals and plants from around the world (Leppakoski, 1994). With the stage set, the constant release of ballast water from the Americas into the Black Sea resulted finally in the successful inoculation of *Mnemiopsis* into Eurasian waters.

Although *Mnemiopsis* has a wide range of temperature and salinity tolerance, its ecology may vary in different parts of the world, even in the Mediterranean system. For example, while it can reproduce all year round in most parts of the Black Sea (deduced from the presence of young individuals at every sampling period between June 1991 and April 1994), it can only survive in the Azov Sea in warmer months. Similarly, *Mnemiopsis* was present only during a short period, April to June, in Mersin Bay, northeastern Mediterranean (Kideys and Niermann, 1993), in contrast to the situation in the Black Sea.

Table 2

Chronology of the first reports of *Mnemiopsis leidyi* in the Black Sea and adjacent Regions.

Year of observation	Season	Method	Area	Abundance	Name used	Source
			A. The Black Sea			
1982	Autumn	scuba	South-East Crimea, near shore	a few specimens	*Bolinopsis sp.*	Pereladov, 1988
1986	Spring	net sampling and submersible observation	Bulgarian coastal waters	a few specimens	*Leucothea multicornis*	Konsulov, 1990; Bogdanova and Konsulov, 1993
1987	Autumn	scuba	South-East Crimea, near shore	rather abundant	*Bolinopsis sp.*	Pereladov, 1988
	Autumn	net sampling	North-Western shelf	a few specimens	*Bolinopsis infundibulum*	Zaitsev *et al.*, 1988, 1990
	Summer, Autumn	diving	North-East (near shore)	rather abundant	*Mnemiopsis leidyi*	Vinogradov *et al.*, 1989
1988	Winter	submersible observation	North-Western shelf	rather abundant	*Mnemiopsis mccradyi*	Zaika and Sergeeva, 1990
	Spring	net sampling and submersible observation	East, central, West, open sea	from a few specimens to rather abundant	*Mnemiopsis leidyi*	Vinogradov *et al.*, 1989, 1990
	Spring	submersible observations	North-Eastern shelf	rather abundant	*Mnemiopsis mccradyi*	Zaika and Sergeeva, 1990; Sergeeva, 1992
	Summer	net sampling	all parts of the sea	abundant	*Mnemiopsis mccradyi*	Zaika and Sergeeva, 1990

Table 2 (cont'd.)

	Summer	net sampling	all parts of the sea	abundant	*Mnemiopsis leidyi*	Vinogradov *et al.*, 1989
B. The Azov Sea						
1988	Autumn		near Kerch Strait	abundant	*Mnemiopsis leidyi*	Vinogradov *et al.*, 1989, Studenikina *et al.*, 1991
C. The Sea of Marmara						
1992	Summer	observation from ship	Bosphorus	abundant	*Mnemiopsis mccradyi*	Kideys and Nierman, 1993
	Summer	scuba diving	Southern part	abundant	*Mnemiopsis mccradyi*	Kideys and Nierman, 1993
	Autumn	net sampling	the whole sea	abundant	*Mnemiopsis leidyi*	Shiganova, 1993
D. Aegean Sea						
1993	Summer	net sampling	off Kusadasi	only one specimen	*Mnemiopsis sp.*	Kideys and Nierman 1994
E. Eastern Mediterranean						
1992	late Spring	net sampling	Mersin Bay	rather abundant	*Mnemiopsis mccradyi*	Kideys and Nierman 1993
1993	Summer ?	net sampling	Syrian coast	a few specimens	*Mnemiopsis leidyi*	Shiganova (pers. comm)

2.2 Distribution, Biology and Ecology of *Mnemiopsis leidyi* in the Black Sea Region

2.2.1 Ctenophore Populations in the Black Sea Before the *Mnemiopsis* Invasion

Before the introduction of *Mnemiopsis leidyi* into the Black Sea, there was only a single species of ctenophore, *Pleurobrachia pileus* (Mordukhai-Boltovskoi, 1969). In contrast, the Mediterranean contains a great diversity of ctenophores (Chun, 1880). Since the Black Sea is connected to the Mediterranean through the Bosphorus, it appears that *P. pileus* is the only Mediterranean species that can survive there, probably because of the great difference in hydrographic conditions between the two regions. It is noteworthy that Shiganova (1993) found *Beroe* sp. in the Sea of Marmara, which lies at the mouth of the Bosphorus in the Mediterranean, and yet species of *Beroe* do not occur in the Black Sea (Mordukhai-Boltovskoi, 1969).

2.2.2 Distribution and Abundance of *Mnemiopsis* in the Black Sea

The first records about *Mnemiopsis* appearance in the Black Sea go back to 1982 (Table 2). The massive growth in populations started in 1988 and at first covered only bays, gulfs and coastal waters. Since spring 1988, its juveniles have been encountered in all open sea areas, and in autumn 1988 its biomass reached 1.5 kg m^{-2} (Vinogradov *et al.*, 1989). During the summer of 1989 the biomass of *Mnemiopsis* increased considerably and its total value for the whole sea attained 10^9 tons, wet weight (Shushkina, Nikolaeva, Lukasheva, 1990). In mid August - early October 1990, *Mnemiopsis* development remained constant (Fig.1). Its abundance reached 10-12 kg m^{-2} at several coastal areas (e.g., Anapa, the south-western Bulgarian coast), but did not exceed 1.5-3 kg m^{-2} in the open sea (Vinogradov *et al.*, 1990, Shushkina and Vinogradov 1991, Zaika and Sergeeva, 1990) (Fig 2).

In 1991, the biomass in the autumn months dropped by 4-6 times, compared with 1989, down to a biomass of 300-800 g m^{-2}. The observations in September-October 1992 and later in autumn 1993 showed that the *Mnemiopsis* biomass remained at the level of late summer and beginning of autumn (October) 1991 (Vinogradov *et al.*, 1993). It is likely that ctenophore development passed through a peak at the end of 1989 and in 1990 and, based on new data, its role in the planktonic community from 1991-93 was reduced. The biomass of *Mnemiopsis* during the peak of its outbreak from autumn 1988 to summer 1990 was approximately the same as that of the jellyfish during the decade from 1979 to 1988 (Fig.3) in comparable units (C_{org}), although its wet weight was several times greater.

According to Ukrainian and Turkish data (Mitlu, 1994), the minimum summer biomass of *Mnemiopsis* in the Black Sea was in 1991 (mean value 130 g m^{-2}), in 1992 (192 g m^{-2}) (Fig. 3), and in 1993 (216 g m^{-2}). In 1994 its average biomass increased to 250 g m^{-2} (Fig.4). The biomass of *Mnemiopsis* of the whole sea was estimated to be 100 million tons in 1994.

The seasonal trends in 1991 in the biomass of *Mnemiopsis* for the open sea community changed little in different areas. In winter (February 1991), its quantity was minimal all over the sea and did not exceed 800 g m^{-2}. Most of the small population was composed of medium-size individuals. By spring (March-April) 1991, the biomass rapidly increased at the periphery of gyres and remained about the same at their centres. By summer (August 1991), the biomass sharply increased due to the growth of juveniles. By autumn 1991 (November), the *Mnemiopsis* population had decreased to values typical of winter

(Vinogradov and Shushkina 1992, Choroshilov 1993) (Fig.5). Thus, observations of 1991-93 showed that *Mnemiopsis* as an intruder was in the planktonic community of the Black Sea. Its population density during these years stabilized at 300 to 800 g m^{-2}.

In its native environment, *Mnemiopsis* populations exhibit long-term fluctuations in their density. Several years of a relatively low density are followed by years when the abundance of *Mnemiopsis* rises by several factors (Fig.6). The same is expected with its population in the Black Sea, as happened in 1994 when the biomass of *Mnemiopsis* in the whole Black Sea, except the Bulgarian and Romanian coastal areas, increased to 0.4 - 4 kg m^{-2}, close to that attained during its first outbreak in 1988-1990. Off the Bulgarian coast an outbreak in 1993 was followed by a second outbreak in the open sea in 1994 (Fig.6). Its density was significantly greater than during the period of its stabilization in 1991-93 (Shiganova, personal communication, Studenikina *et al.*, in preparation; Kideys, 1994). By late winter of 1995 rather dense populations of *Mnemiopsis* (0.5-1.6 kg m^{-2} of biomass in the water column) were recorded in shallow waters opposite Anapa (North East Black Sea), even during its seasonal minimum by early February 1995 (Sorokin, pers. comm.). This meant that a rather dense bloom of *Mnemiopsis* was expected in summer-autumn of 1995.

2.2.3 *Mnemiopsis leidyi* Distribution and Abundance in the Black Sea Region: Azov Sea

The appearance of *Mnemiopsis* in the Azov Sea was recorded first in August 1988. The available data (Volovik *et al.*, 1993) confirm that it is present in the Azov Sea only in the warm season of the year. Hence, because it does not survive the winter in this basin, every year its populations are being reintroduced from its originating basin - the Black Sea - where it reproduces. *Mnemiopsis* will be reintroduced during each spring-summer period as long as it exists in the "mother" sea (Volovik *et al.*, 1991). The penetration of *Mnemiopsis* into the Azov Sea from the Black Sea proceeds between April and July. The higher the density in the Black Sea, the easier this happens. After its penetration, via the Kerch strait on the inflowing current, the ctenophore population rapidly grows and within several weeks after its penetration spreads through the whole sea areas and attains a high biomass.

These events cause grave negative changes in the ecosystem of the sea. The scale of this impact largely depends upon the time of the first penetration of *Mnemiopsis*. When it appeared in the Azov Sea in 1989-1990, early in April-May, it reduced the zooplankton stock before the end of June - beginning of July. By grazing intensively on fish eggs and larvae, it also drastically undermined the reproduction of kilka and anchovies. While exterminating the meroplanktonic larvae of benthic animals, it displayed a pronounced damaging impact upon the zoobenthos. When the density of the Black Sea *Mnemiopsis* population decreased by 1993-early 1994, it penetrated into the Azov Sea late - in June-July. This made it possible for the populations of small pelagic fish to spawn safely and form significant stocks which were used by the fishery. Their catch was estimated at 15-25000 tons in 1994. By the end of the summer, the zooplankton stock was grazed by the ctenophores practically to zero (Volovik *et al.*, 1993). In 1993, the bloom of *Mnemiopsis* continued from the end of June until late November. Its total biomass in the whole sea was estimated to be over 20 million tons, close to its maximum abundance attained in 1989 (30 x 10^6 tons).

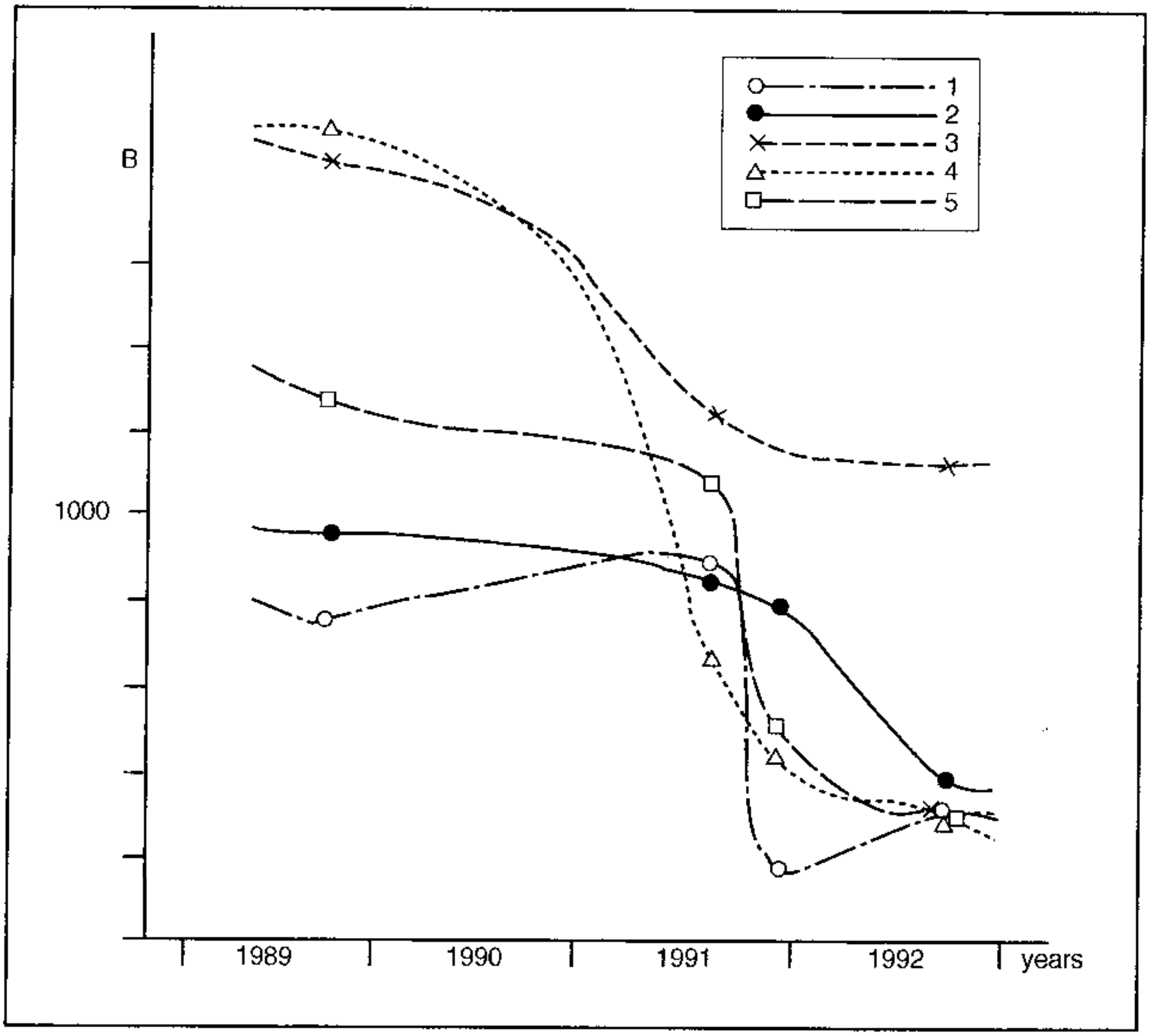


Figure 1: Changes in the biomass (Kg/m^2) of *Mnemiopsis leidyi* in five locations of open Black Sea.
1 - centre of western gyre; 2 - south of Crimea (convergence area); 3 - centre of eastern gyre; 4 - in the stream of the Black Sea current opposite to Gelendjik; 5 - open sea (opposite to Novorossijsk). (After Vinogradov and Shushkina, 1992).

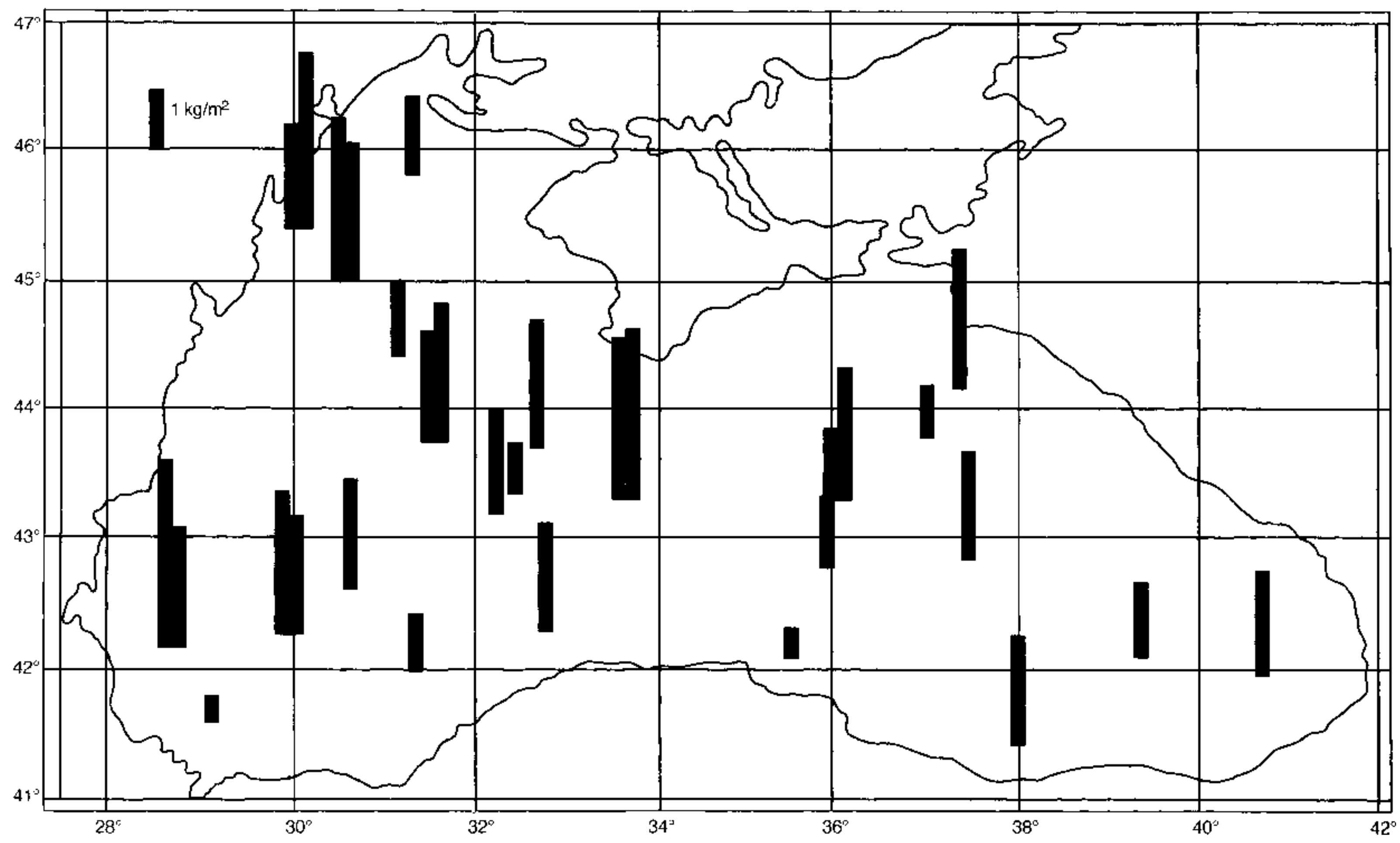


Figure 2: Spatial distribution of the *Mnemiopsis* biomass (kg m^{-2}) in the Black Sea in July-September, 1989. Based on Vinogradov and Shushkina, 1992.

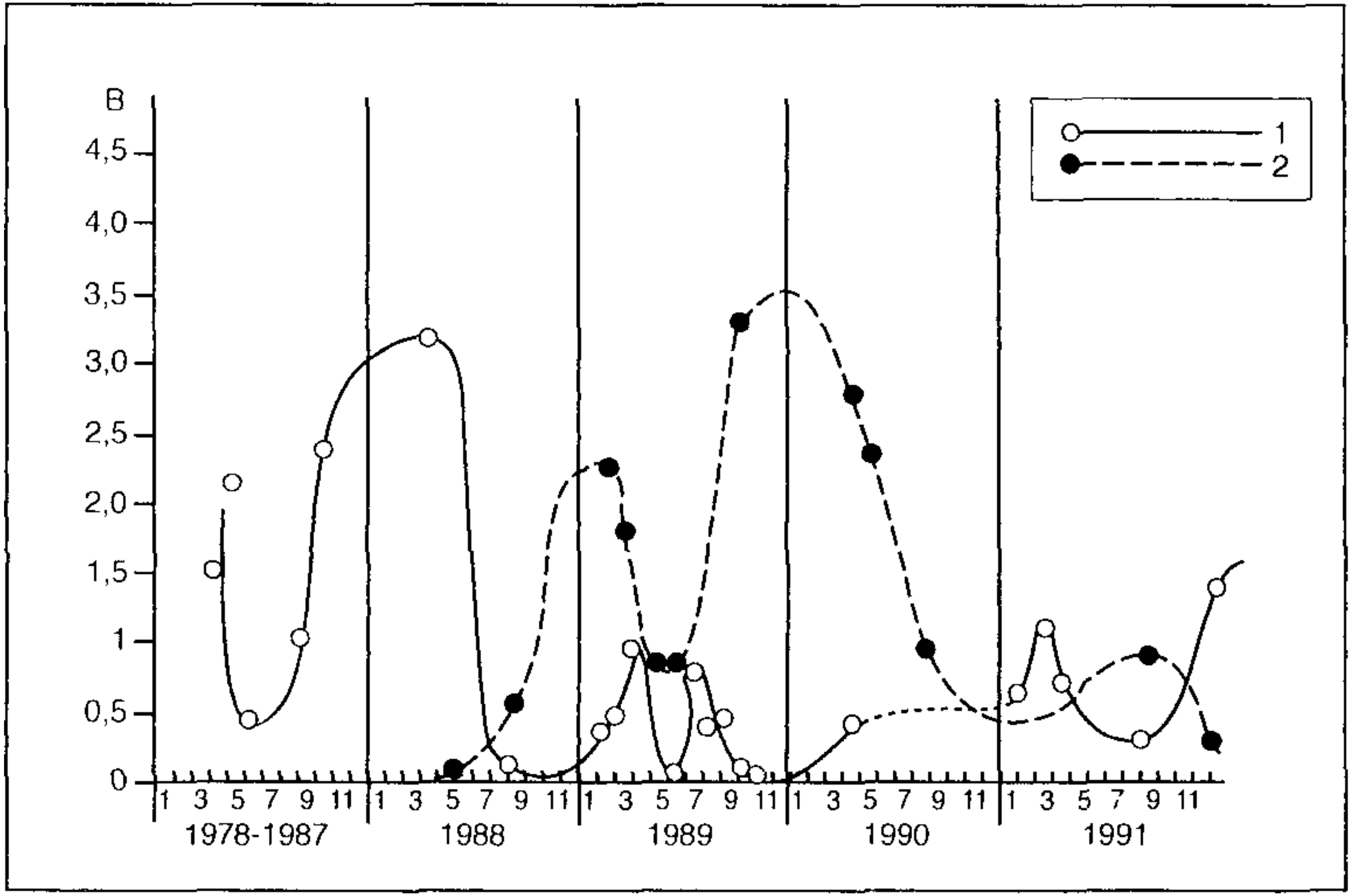


Figure 3: The long-term and seasonal changes of biomass (B, g C/m²) of the jellyfish *Aurelia aurita* (1) and *Mnemiopsis* (2) in open areas of the Black Sea. Each point corresponds to data of the different expeditions on different ships ("Vitjaz", "Dimitry Mendeleev", "Rift", "Hydrobiolog", "Jantar" and "Academic Petrov"). After Vinogradov and Shushkina, 1992.

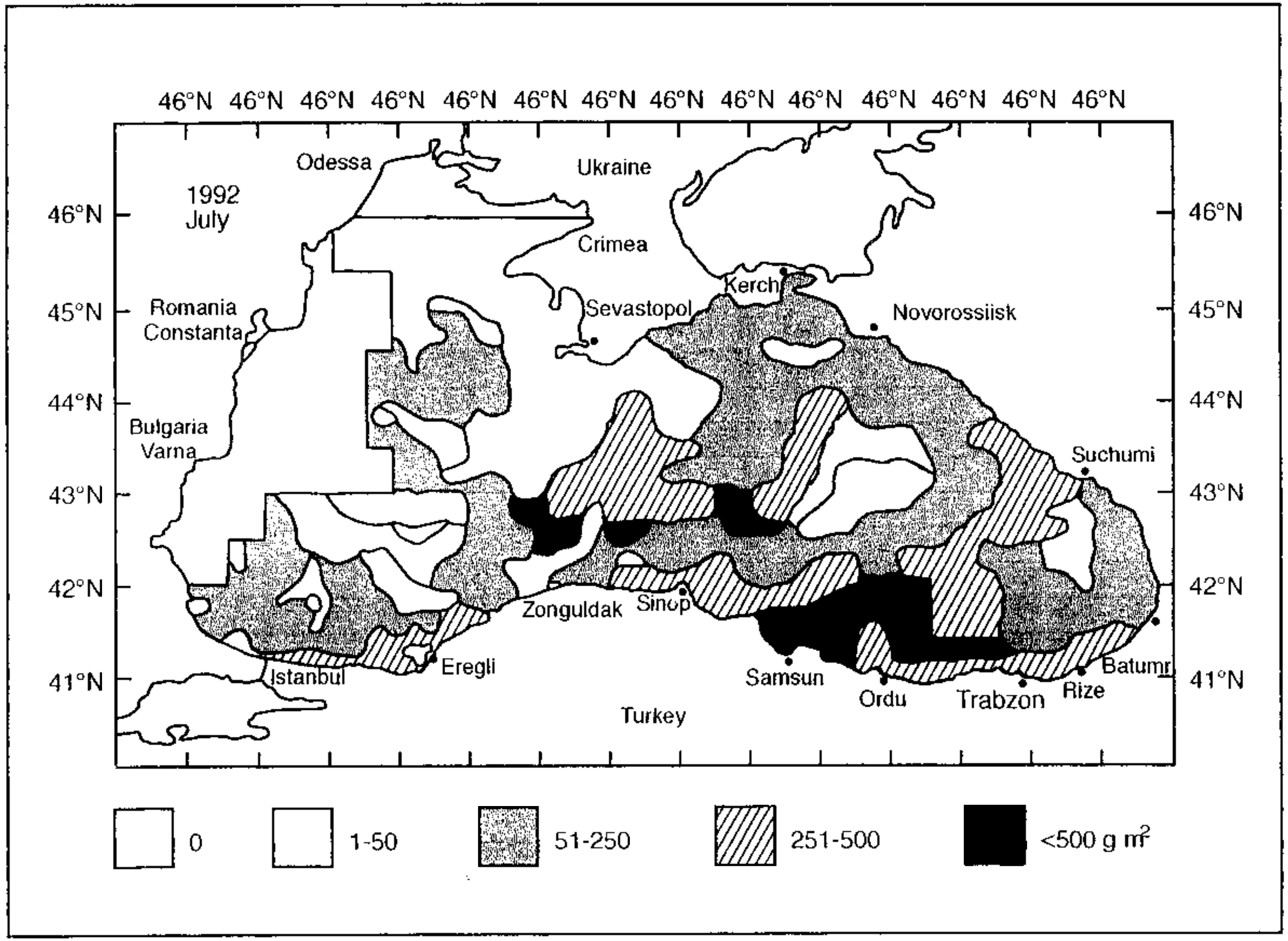


Figure 4 Spatial distribution of *Mnemiopsis* sp. biomass (wet weight, g m^{-2}) in the Black Sea. After Mitluetal, 1994.

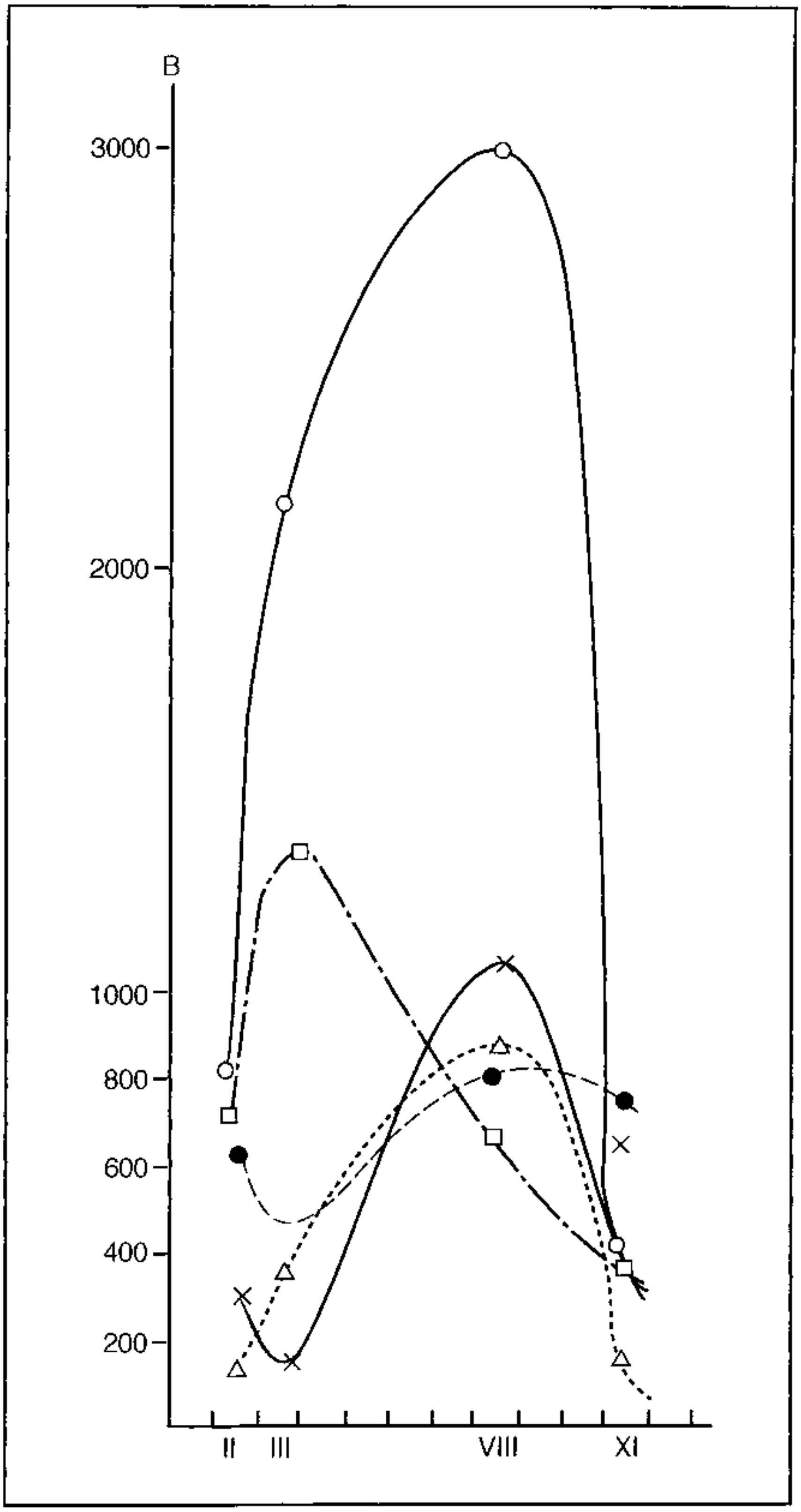


Figure 5: The seasonal dynamics of the *Mnemiopsis* biomass (g m^{-2}) in key points of the Black Sea. For designation of areas, see Fig.1. After Vinogradov and Shushkina, 1992.

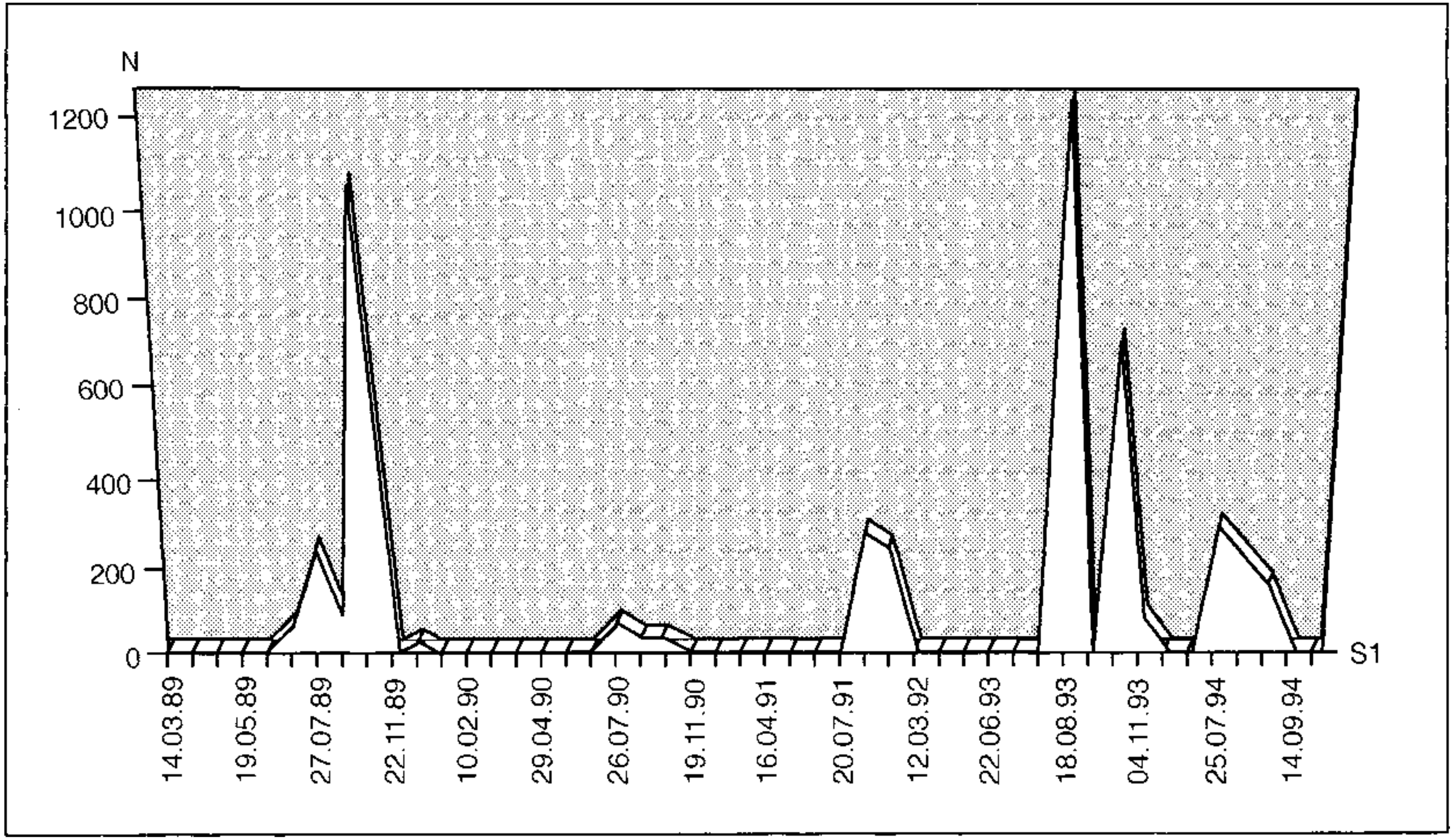


Figure 6: Long-term trends in the numerical abundance (N, specimens m^{-3}) of *Mnemiopsis* in Bulgarian coastal waters. After Konsulov, 1989, 1990.

2.2.4 *Mnemiopsis leidyi* in the Adjacent Regions: Marmara and Mediterranean Seas

In October 1992 an extremely vigorous outbreak of *Mnemiopsis* was recorded in the Marmara Sea. Its biomass reached over 12 kg m^{-2} in its North-West part. An average biomass of ctenophores in the sea was over 4 kg m^{-2} (Shiganova, 1993, Fig.7). The zooplankton in the upper warm water layer was grazed intensively by them. In 1993 by late summer the *Mnemiopsis* was still present in this sea but its density was much less (Kideys and Niermann, 1994).

Mnemiopsis had already been observed in bulk quantities in the eastern Mediterranean around Mersin, in May 1992 (Kideys and Niermann, 1993). However, the presence of this population was short, from April to late June, then it disappeared. *Mnemiopsis* was observed again in the eastern Mediterranean, along the Syrian coast, in September 1993 (T. Shiganova, pers. communication).

2.2.5 Special Features of the Biology of *Mnemiopsis* in the Black Sea Region

Mature specimens of *Mnemiopsis* spawn at night (Zaika and Sergeeva, 1994) in summer temperatures of 19 to 23°C. Embryonic development takes about 20 hours. The maturing of gonads and the subsequent spawning can take place only at a reasonably high food concentration of medium size copepods (up to 100 spec. l^{-1}). The feeding habits of *Mnemiopsis* are characterized by an intensive rate at night. The composition of gut food correlates with local plankton composition. For example in the Azov Sea, the gut contents of *Mnemiopsis* consisted of cladorerans (6-10 per cent), meroplanktonic larvae (20 per cent), insects (10 per cent), fish larvae (2 per cent) and about 10 per cent of detritus (Volovik *et al.*, in preparation). In shelf waters the population of *Mnemiopsis* was estimated to graze up to 70 per cent of total ichthyoplankton stock (Tsikhon-Lukanina *et al.*, 1993).

2.2.6 Forecast of Future Impact of *Mnemiopsis leidyi* Populations in the Black and Azov Seas

The massive bloom of *Mnemiopsis leidyi* in 1989-1990 was followed by several years in which its densities decreased dramatically. This led a number of investigators to conclude that its population levels had stabilized (Mutlu *et al.*, 1994). However, in 1994 it was found that population levels had again increased, approaching those found during the previous peak years (Shiganova, pers. comm.). Thus, patterns of its abundance resemble those in the Americas, with intensities and durations of abundance varying unpredictably from year to year (Kremer, 1994). The dramatic increase in population density in 1994 strongly supports the necessity to develop control measures.

2.3 Distribution, Biology and Ecology of *Mnemiopsis leidyi* in the Americas

There can be little doubt that species of *Mnemiopsis* were formerly endemic to the eastern seaboard of the Americas. The first two described species that clearly belong to this genus were *Mnemia schweiggeri* Eschholtz, 1825, and *Alcinoe vermiculata* Rang, 1828, both collected in Rio de Janeiro harbour. Another species, *Alcinoe rosea* Mertens, 1833, was described from the South Atlantic off the coast of Argentina. The type species of the genus *Mnemiopsis, M. gardeni* Agassiz, 1860, was described from Charleston harbour, United States. *Mnemiopsis leidyi* Agassiz, 1865, was collected near Woods Hole, and *M. mccradyi* Mayer, 1900, was first described from Charleston harbour. Gould (1841) reported a

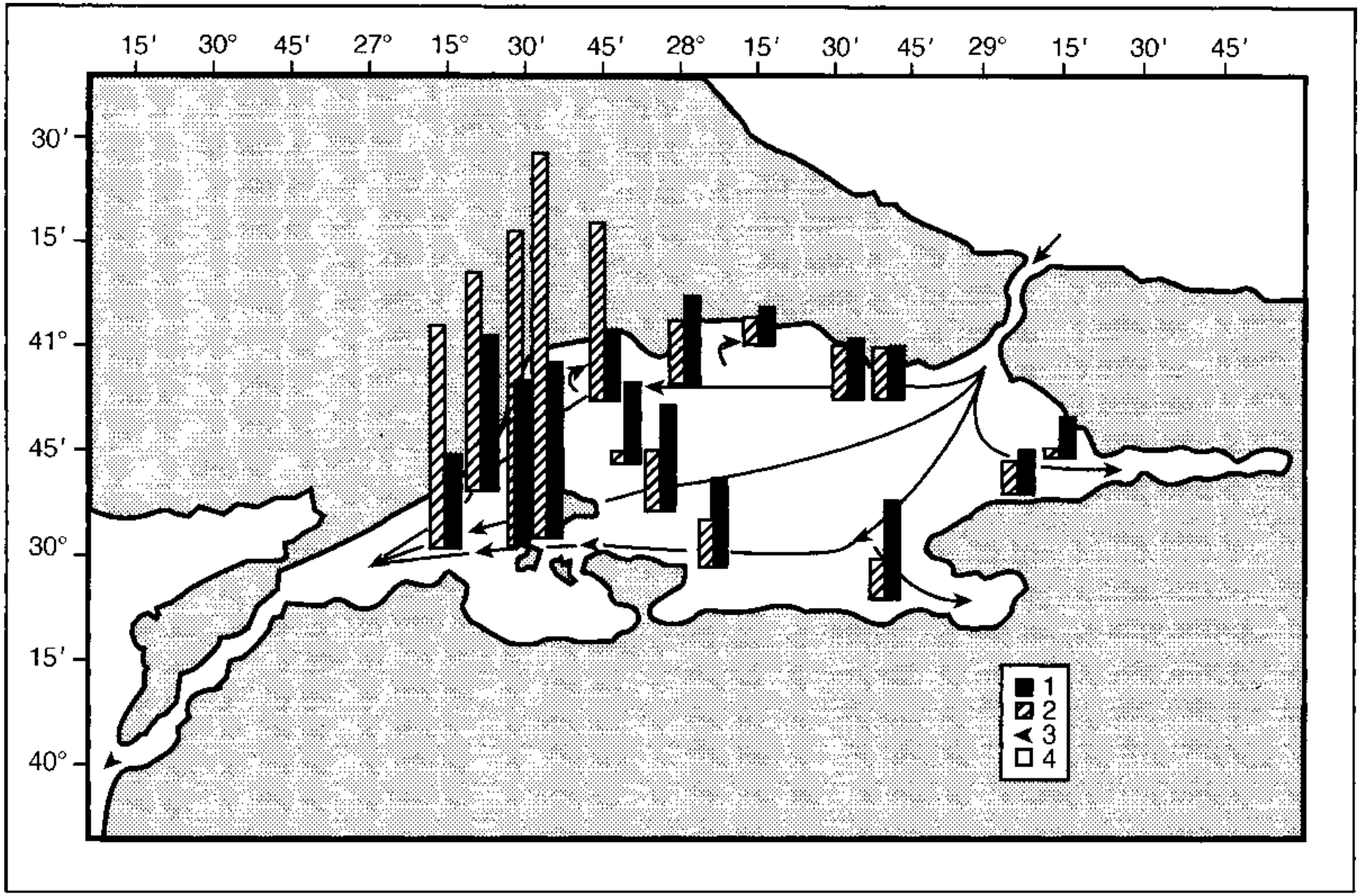


Figure 7: The distribution of the *Mnemiopsis* biomass in the Sea of Marmara in October 1992: 1 - biomass of ctenophores after the BR net tows; 2 - biomass of ctenophores after tows of the RS-net; 3 - direction of currents; 4 - scale of column, 1 kg m^{-2} (data by Shiganova, 1993)

ctenophore which he called *Alcynoe vermicularis* Rang from the Woods Hole, Massachusetts region, which probably represents the first report of the genus in the northern hemisphere. At present, the taxonomy of the genus is unclear, since there are no good morphological characters to separate the six nominal species. In recent literature, two species have been recognized, *Mnemiopsis leidyi* and *M. mccradyi*. They are distinguished by the greater rigidity of the mesogloea and the presence of prominent papillae on the body of *M. mccradyi*, and by differences in colour. These characters appear to depend on the environmental conditions under which the animals develop, and thus for the purposes of this report, they are considered subspecies of a single species, provisionally called *Mnemiopsis leidyi*. This ctenophore has a wide range in the Americas, from the Woods Hole region in the north to southern Argentina in the south (Table 3).

In the Americas, species of *Mnemiopsis* are usually found close to shore, in bays and estuaries (for example, see Miller, 1974), although they have occasionally been collected several hundred kilometres offshore (Mertens, 1833; Harbison *et al.*, 1978). They are able to tolerate a wide range of salinity and temperature, and can live and reproduce in temperatures ranging between 1.3° C (Burrell and Van Engel, 1976) and 32° C (Baker, 1973) and in salinities ranging between 3.4 ppt (Miller, 1974) and 75 ppt (Simmons, 1957). They survive well in oxygen-poor environments (Burrell and Van Engel, 1976). They are most abundant in brackish waters with high levels of particulate material, and appear to be little affected by contaminants. The only factors which appear to restrict their rapid population growth are temperature, the availability of food and the presence of predators. Although they can survive for long periods without food, they reproduce prolifically when concentrations of food are high and temperatures are above 20° C (Kremer *et al.*, 1986; Reeve *et al.*, 1989). Without food, *Mnemiopsis leidyi* simply reduces in size to support its metabolism (Reeve *et al.*, 1989). This makes it an ideal candidate for transport in the ballast water of ships. It also means that the population growth dynamics of the species cannot be determined from size analysis, an important point regarding any planned monitoring strategy (see Section 6.1).

Mnemiopsis ingests virtually any organism that it is able to capture with its oral lobes, including holoplanktonic organisms, the planktonic larvae of benthic organisms, and the eggs and larvae of fishes (*e.g.* Nelson, 1925; Main, 1928; Mountford, 1980; Monteleone and Dugay, 1988; Tsikhon-Lukanina *et al.*, 1993). Like most lobate ctenophores, *Mnemiopsis leidyi* feeds superfluously (Harbison *et al.*, 1978). Even when the stomodaeum is full, it continues to capture prey, regurgitating large quantities of undigested plankton in a bolus of mucus. Thus, its deleterious impact on zooplankton and micronekton greatly exceeds its ability to assimilate captured prey.

In common with other ctenophores, *Mnemiopsis* is a simultaneous hermaphrodite. This means, in theory, that a single animal could successfully invade a new area. This attribute, together with its ability to reproduce over a wide range of environmental conditions, makes it well-suited for transplantation by the ballast water of ships.

Table 3

Locations where the six nominal species that can be ascribed to the genus *Mnemiopsis* have been collected in the Americas, arranged from north to south. Positions given are approximate.
Key to abbreviations of species: (G) = *Mnemiopsis gardeni*; (L) = *Mnemiopsis leidyi*; (M) = *Mnemiopsis mccradyi*; (R) = *Alcinoe rosea*; (S) = *Mnemia schweiggeri*; (V) = *Alcinoe vermiculata*; (?) = *Mnemiopsis* sp. (From Harbison and Volovik, 1994)

Location	Position	Species	Reference
Narragansett Bay, RI	41°40' N, 71°20' W	L	Deason (1982)
Naushon Island, MA	41°30' N, 70°40' W	L	Agassiz (1865)
Delaware Bay	39°00' N, 75°00' W	L	Cronin *et al.* (1962)
North Atlantic	38°40' N, 66°20' W	M	Harbison *et al.* (1978)
Chesapeake Bay	37°10' N, 76°20' W	L	Burrell & Van Engel (1976)
Pamlico River, NC	35°20' N, 76°30' W	L	Miller (1974)
Core Sound, NC	34°50' N, 76°30' W	G	Mayer (1912)
Charleston Harbor, SC	32°50' N, 79°50' W	M	Mayer (1900)
Charleston Harbor, SC	32°50' N, 79°50' W	G	Agassiz (1860)
Bermuda	32°10' N, 66°00' W	L	Fewkes (1883)
Pensacola Bay, FL	30°30' N, 87°10' W	M	Cooley (1978)
Horn Island, MS	30°20' N, 88°40' W	M	Richmond (1962)
Mississippi Sound	30°20' N, 89°00' W	M	Phillips *et al.* (1969)
St. Augustine, FL	30°00' N, 81°20' W	M	Dubas *et al.* (1988)
St. George Is., FL	29°40' N, 85°00' W	M	Menzel, (1971)
Breton Sound, LA	29°30' N, 89°10' W	?	Curzon du Rest (1963)
Galveston Bay, TX	29°30' N, 94°40' W	M	Pullen (1960)
Aransas Bay, TX	28°00' N, 97°00' W	M	Whitten *et al.* (1950)
Laguna Madre, TX	27°30' N, 97°20' W	M	Simmons (1957)
West Lake, FL	25°20' N, 81°00' W	?	Davis and Williams (1950)
Biscayne Bay, FL	25°30' N, 80°10' W	M	Woodmansee (1958)
Cuba	22°00' N, 80°00' W	L	Ortiz Touzet (1990)
Golfo de Batabanó	22°00' N, 82°00' W	?	Campos (1981)
Mayaguez Harbor	18°10' N, 67°10' W	M	Larson (1986)
Kingston, Jamaica	17°50' N, 76°50' W	M	Mayer (1912)
Cienaga Grande	10°30' N, 74°30' W	?	Avila de Tabarés (1978)
Cartagena Bay	10°20' N, 75°30' W	L	Moncaleano and Niño (1979)
Blue River, Trinidad	10°40' N, 61°20' W	?	Bacon (1971)
Rio de Janeiro	23°00' S, 43°10' W	S	Eschholtz (1825)
Rio de Janeiro	23°00' S, 43°10' W	V	Rang (1828)
São Sabastião	24°00' S, 45°00' W	M	Anderson, P.A. (pers comm)
Rio del la Plata	35°00' S, 57°00' W	M	Ramírez (1973)
Bahía Samborombon	36°00' S, 57°00' W	M	Mianzan *et al.* (1989)
Bahía Blanca	39°00' S, 62°00' W	M	Mianzan and Sabatini (1985)
Peninsula Valdez	43°00' S, 64°00' W	L	Alheit *et al.* (1991)
South Atlantic	44°10' S, 56°30' W	R	Mertens (1833)

2.3.1 Diseases, Parasites and Predators of *Mnemiopsis leidyi*

Nothing is known about diseases of ctenophores or of *Mnemiopsis leidyi* (Lauckner, 1980; Peters, 1993). No viral, bacterial, fungal or protozoan agents specific to ctenophores have been identified.

Metazoan parasites do not appear to reduce stocks of *Mnemiopsis leidyi* in the Americas. The burrowing anemone, *Fagesia* (=*Edwardsia*) *lineata*, is found as a parasite of *Mnemiopsis leidyi* in the northeastern United States (Crowell, 1976). However, this anemone apparently causes little damage to the ctenophore, and is frequently found living freely in the water. Sometimes blooms of this anemone can be so large as to affect the suitability of beaches for swimming. These anemones, like other cnidarians, have stinging cells capable of creating intense reactions in swimmers. In some cases, beaches on Long Island (Northeastern United States) have been closed because of dense concentrations of this anemone (Freudenthal, 1991).

Some members of the hyperiid amphipod families, Hyperiidae and Oxycephalidae, are obligate parasites on ctenophores during their juvenile stages, and members of the latter family have been found on *Mnemiopsis leidyi* in the open sea (Harbison *et al.*, 1977; 1978). Since hyperiid amphipods do not occur in estuarine regions, they could exert little control on the bulk of the *Mnemiopsis leidyi* populations in the Americas.

Parasitic trematode flatworms are frequently found in ctenophores, and may, together with food shortages and predation, reduce *Pleurobrachia pileus* populations (Yip, 1984). Comparable information is not available for *Mnemiopsis leidyi*.

Invertebrate and vertebrate predators on *Mnemiopsis leidyi* are known in the Americas, and members of both groups have been reported to control its population density. The scyphomedusa, *Chrysaora quinquecirrha*, feeds voraciously on *Mnemiopsis leidyi* in Chesapeake Bay (Feigenbaum and Kelly, 1984), as does an endemic American species of the ctenophore genus *Beroe* (Burrell and Van Engel, 1976). Both species have been reported to control *Mnemiopsis leidyi* populations. Whereas *Chrysaora quinquecirrha* feeds on a wide variety of zooplankton and larval fishes, the diets of all species of *Beroe* are restricted to gelatinous zooplankton, particularly salps and ctenophores (Swanberg, 1974; Greve *et al.*, 1976; Matsumoto and Harbison, in press; S. Tamm, pers. comm.). Both of these invertebrates have reproductive rates that closely approximate the reproductive rates of *Mnemiopsis leidyi*. This means that these predators can respond to increases in prey density very rapidly.

There are numerous vertebrate predators on ctenophores, including fishes, turtles and seabirds (Harbison, in preparation). The latter two groups have not been shown to be important predators on *Mnemiopsis leidyi*, however.

In North America, fishes in the genus *Peprilus*, the butterfish, feed extensively on gelatinous zooplankton. Two of the three species found there, *P. burti* and *P. triacanthus*, are known to feed on *Mnemiopsis* (Phillips *et al.*, 1969; Oviatt and Kremer, 1977). The latter authors suggested that *P. triacanthus* controlled populations of *M. leidyi* in Narragansett Bay, Rhode Island, U.S.A. Other fish that are known to eat *M. leidyi* in North America include *Chaetodipterus faber*, *Alosa aestivalis*, and *Squalus acanthias*. Many other fish are known to eat ctenophores on the Atlantic coast of the Americas, and probably eat *M. leidyi*. The uncertainty in identification is due to the difficulty of identifying ctenophore fragments to genus, in fish stomachs.

3 Causes of the Ctenophore Outbreaks and their Relationship with Marine Environmental Quality

The ecological catastrophe which developed in the Black Sea at the outbreak of the predatory ctenophore *Mnemiopsis* in 1988-1990 in part was associated with the destabilization and degradation of the Black Sea ecosystem that had been occurring in this basin over several decades. Intrinsic features of the Black Sea are an isolated basin, subjected to continuing transformation from freshwater to marine conditions, and a low diversity of marine organisms (Sorokin, 1983). However, it is the permanently stratified (meromictic) basin, in which a larger part of the bottom water column is excluded from the ecosystem, which makes it most vulnerable to destabilization. Normally marine ecosystems contain a great variety of species, and the indigenous predators may be selected to graze on invading organisms and thus control their population density (Pimm, 1989). However, in ecosystems with a low diversity of species such as the Black Sea, predators are limited. The processes of ecological destabilization of the Black Sea therefore could enhance the productivity of invading species.

Since the late 60s, there have been a number of dramatic impacts on the Black Sea ecosystem that have 'set the scene' for the invasion by *Mnemiopsis leidyi* in the pelagic biome. Among these are:

- the impacts of intensive industrial fishing (e.g. Ivanov and Beverton 1985);
- water extraction and barrages affecting estuarine salinities (Sorokin 1982; Tolmasin 1985);
- eutrophication of the marine ecosystem, especially from incoming rivers (Mee 1992).

Many changes also resulted from a combination of these factors (Caddy and Griffith 1990; Caddy 1993, Zaitsev 1993; G.F. C. M. 1993). For example:

- depletion of top predators (bonito, bluefish, turbot, marine mammals, mackerel) reduced predatory pressure on the small pelagic fish biomass; however this may also have resulted from pollution impacts on spawning and migration;
- Decline in demersal fish, benthos and macrophytes occurred as a result of nutrient overloading.

The earliest stages of this process, however, resulted in increases in biomass of small pelagic fish (Ivanov and Beverton 1985) and led to *Aurelia* outbreaks in the late 1970s. In addition, changes of river discharges especially in the Northern Black Sea, affected anadromous fish migration and led to increases in salinity of the Azov Sea.

Since the early 70s, a rapid rise in nutrients and organic eutrophication (Fig. 8) and chemical pollution started due to transportation, construction, booming tourism, the use of pesticides and fertilizers. From the period 1970-80, riverine and local discharges of pollutants have increased considerably. The Danube makes a particularly large contribution (Mee 1992). As a result, nutrients increased in the large NW part of the Black Sea by an order of magnitude compared with 1965 (Sorokin 1982; Zaitsev 1993). The continuing phytoplankton "blooms" were triggered and water over the NW shelf became turbid. The major biofiltering and oxygen-producing communities in this part of the Sea - the Phyllophora field and the *Mytilus* biocoenose - were degraded due to light and oxygen deficiencies (Zaitsev 1992, 1993) (Fig 9).

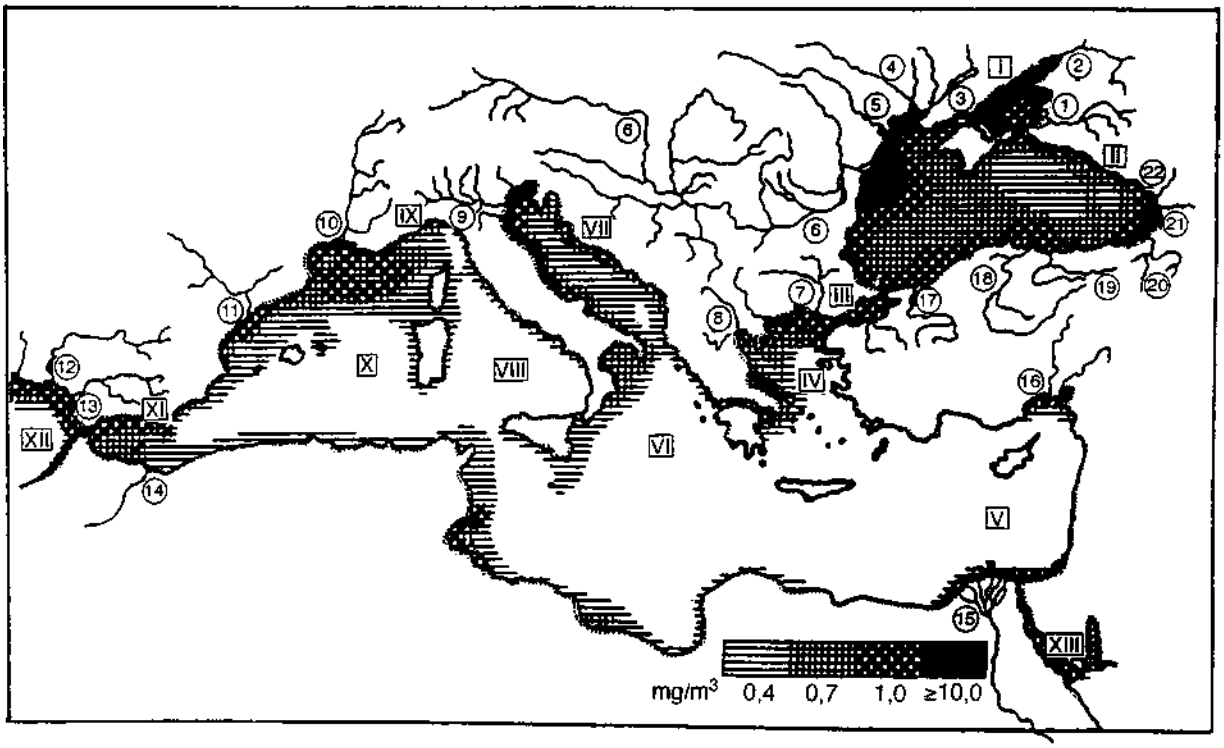


Figure 8: Cultural eutrophication of the Mediterranean basin (From Zaitsev, 1991).

Seas:

I. Sea of Azov
II. Black Sea
III. Sea of Marmara
IV. Aegean Sea
V. Levantine Sea
VI. Ionian Sea
VII. Adriatic Sea
VIII. Tyrrhenian Sea
IX. Ligurian Sea
X. Algero-Provencal Basin
XI. Alboran
XII. Atlantic Ocean
XIII. Red Sea

Main Rivers:

1. Kuban
2. Don
3. Dnepr
4. Southern Bug
5. Dnestr
6. Danube
7. Maritza
8. Vardar
9. Po
10. Rhône
11. Ebro
12. Guadiana
13. Guadalquivir
14. Moulouya
15. Nile
16. Ceyhan
17. Sakarya
18. Kizil Irmak
19. Yesil Irmak
20. Coruh
21. Rioni
22. Inguri

Figure 9: Progressive reduction of the Zernov's "Phyllophora field" on the NWS in 1950s (·············), 1960s (—·—·—), 1970s (– – – – – –) and 1980s (————). After Zaitsev 1993.

The sedimentation of dead phytoplankton, *Noctiluca* and other pelagic organisms resulted in anoxia and H_2S in the bottom water layer in areas of the NW shelf from 1973 to present. The bottom anoxia killed about 35 million tons of *Mytilus*, thus drastically decreasing the activity of this major biofilter of the Black Sea (Zaitsev, 1992). The species diversity of macrobenthos at depths of 50 to 120 m decreased 3-5 times. The lower border of the macrobenthos distribution also moved deeper (110-125 m) (Zaika, 1990).

After this time, uncontrolled by a biofilter, the rise in phytoplankton density in the NW Black Sea was prolonged, and increased: 10-20 times for phytoplankton and for *Noctiluca* - 10 times. The load of phytoplankton and nutrients was spread by the main circular current over the western and eastern parts of the sea and the whole sea changed to a mesotrophic-eutrophic condition. Up to 1985-87, the concentration of phosphate at 100 m depth increased 2 to 2.5 times, and the primary production and microbial biomass increased 3 to 5 times. The biomass of zooplankton and small planktivorous fish also increased.

Thus, the invasion of *Mnemiopsis leidyi* in the 1980s met a high standing stock of pelagic zooplankton, whereas a heavily exploited small pelagic fish population, with annual exploitation rates of up to 50 per cent or more, competed with *Aurelia* for the role of dominant primary carnivore (Zaitsev and Polischuk, 1984, Vinogradov 1992) (Fig.10). Such high exploitation rates of traditionally important zooplanktivores (anchovy, horse mackerel, kilka, etc) may have acted jointly, perhaps synergistically, with eutrophication to open up an ecological niche for the comb jelly predator in the pelagic ecosystem of the Black Sea. This role was first filled by *Aurelia* and then by *Mnemiopsis*. A summary of the key events was described by Zaitsev (1993) and is shown in Fig.11.

It should also be noted that another pronounced impact of *Mnemiopsis* predation pressure was on the seasonal dynamics of *Sagitta setosa* populations. The early spring rise in their biomass relates to the rapid growth of large, mature individuals. The death of the large-sized individuals of *Sagitta* after spawning, and the grazing on juvenile *Sagitta* by *Mnemiopsis* resulted in a sharp reduction of the *Sagitta* population in the summer down to several mg or several tenths of mg/m^2. In contrast to other small opportunistic zooplankton, the density of the *Sagitta* populations did not increase during the autumn decrease of *Mnemiopsis*.

4 Alteration of the Black Sea Ecosystem by the Ctenophore Invasion

4.1 Some General Features of the Black Sea

The Black Sea ecosystem has many unique features of its oceanography and fauna and flora, yet it is a highly changed and disturbed system due to extensive pollution, coastal development, fishing and introduced species, including *Mnemiopsis*. In such a system, there can be many cumulative or interactive effects on water quality and on key fisheries species. It is important to note the difficulty of separating the magnitude of the effects on the ecosystem caused by an abundance of *Mnemiopsis* from effects caused by increasingly deleterious water quality, the various intensive fisheries, and less tangible stresses such as climate change and increased UV radiation. The following sections describe the impact of *Mnemiopsis* on the pelagic ecosystem and on selected fisheries species, while fully recognizing the difficulties of establishing definitive cause-effect relationships under natural marine conditions.

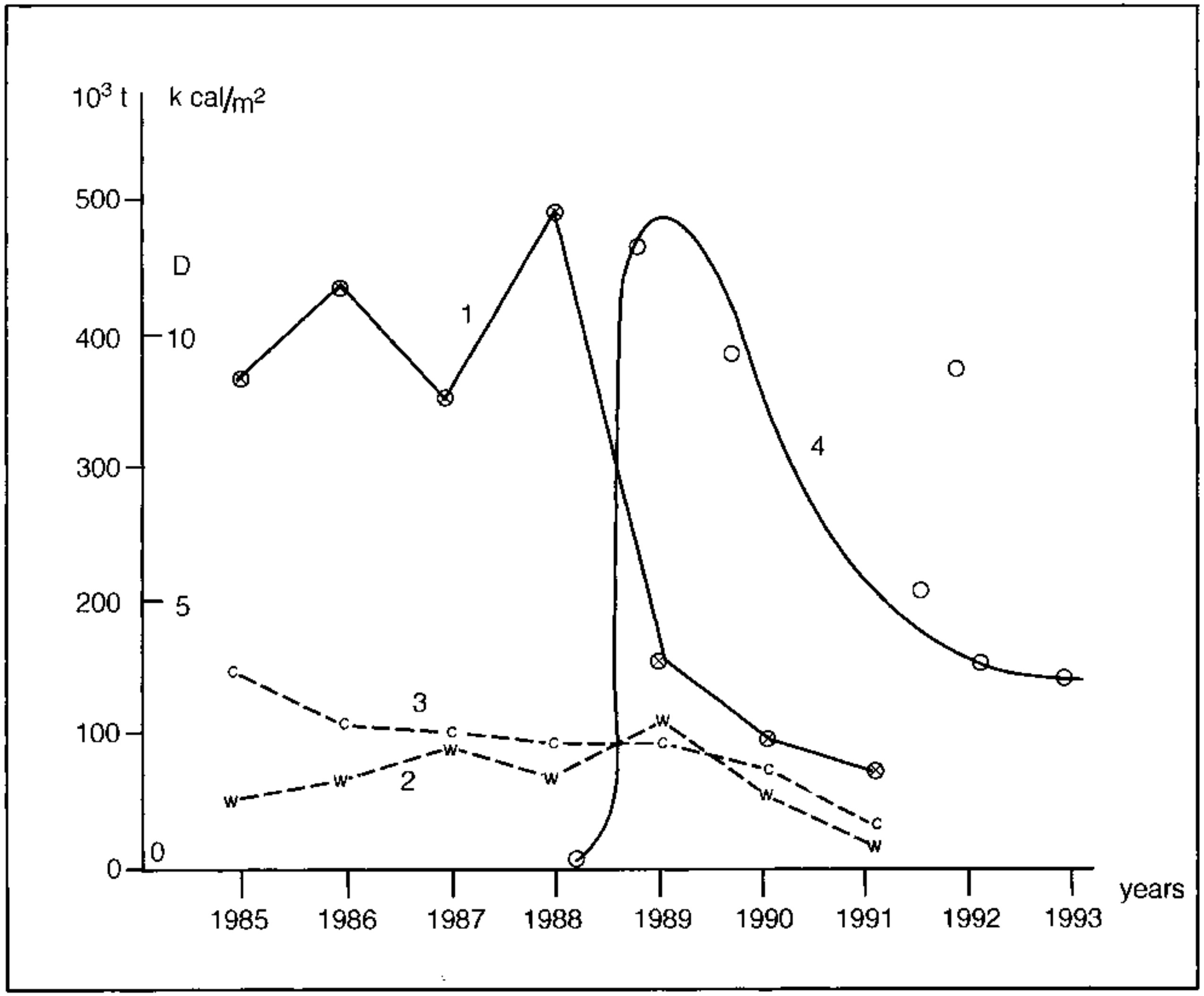


Figure 10: The catches (10^3t) of main commercial planktophagous fish (1-anchovy; 2-sprats; 3-horse mackerel) in the Black Sea (FAO, Rome) and mean summer biomass (kcal/m^2) of 4-*Mnemiopsis* (Vinogoradov *et al.*, 1995).

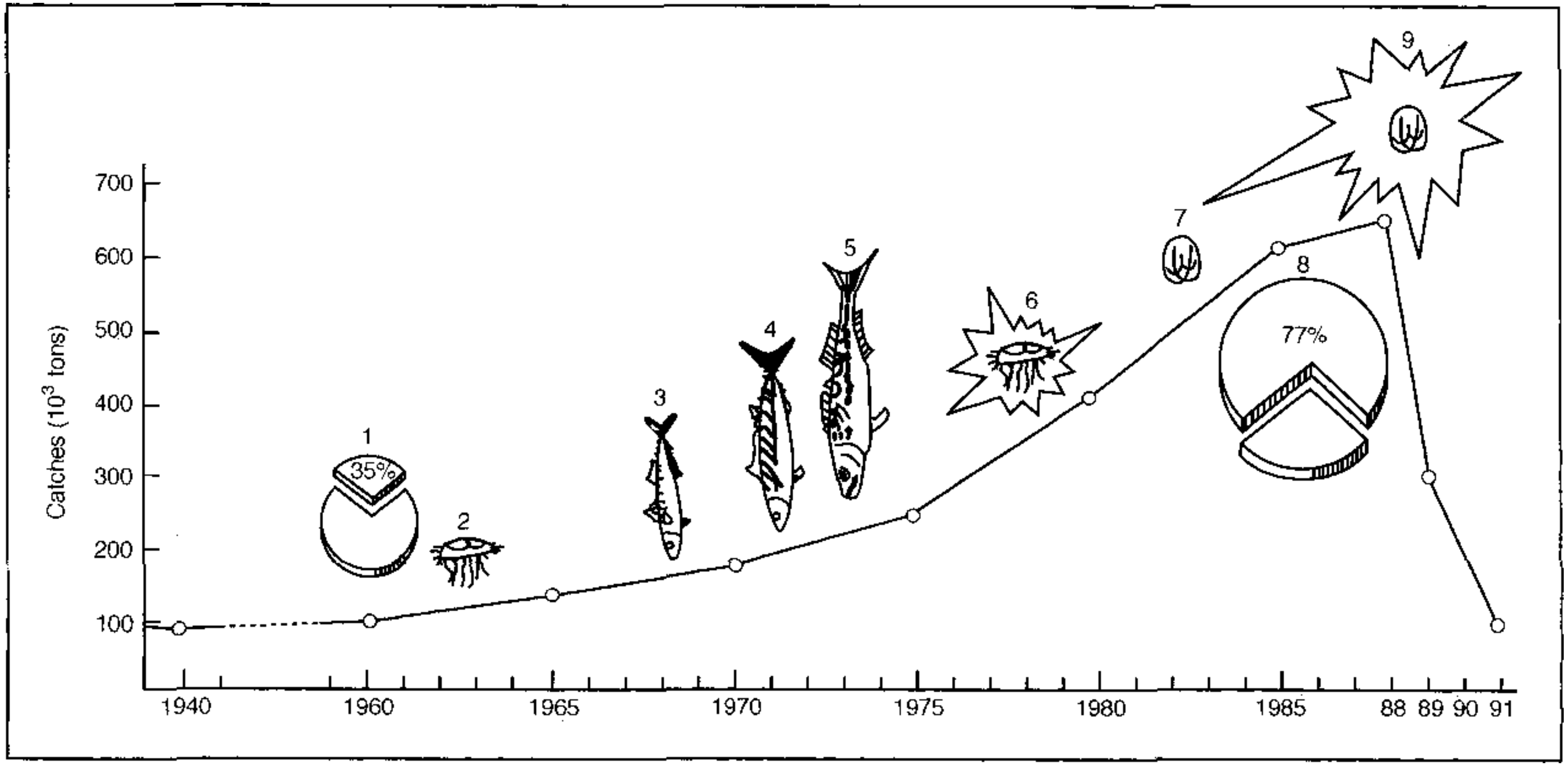


Figure 11: Fishery catches of Black Sea countries and some important ecological events in the Black Sea in 1940-1991 (Zaitsev 1993):

Legend: 1 - The percentage of anchovy and sprat in total catch; 2 - Total biomass of the moonjelly *Aurelia urita* in the Black Sea reached up to one million tons; 3 - The end of fishery for mackerel in the NWS area; 4 - The end of fishery for bonito in the NWS area; 5 - The end of fishery for bluefish in the NWS area; 6 - Outburst of the *Aurelia urita*. Total biomass in the Black Sea reached up to 300-500 million tons; 7 - First single specimens of the comb jelly *Mnemiopsis leidyi* in the Black Sea are observed; 8 - The percentage of anchovy and sprat in total catch; 9 - Outburst of the *Mnemiopsis*. Its total biomass in the Black Sea reached up to 700 million tons.

The Black Sea is a meromictic basin that receives freshwater inputs from many large rivers on its northern and eastern margins, and is connected to the brackish Azov Sea and the largely hypersaline Sea of Marmara. The major part of the area of the Black Sea is divided into three layers: an upper mixed layer, an intermediate layer, and a deep layer. The upper mixed layer exists only in summer when the seasonal thermocline forms. The upper layer has temperatures of 22-26° C, salinity of 17.5-18.3 ppt, and dissolved oxygen of 7-8 mg/l. Below the seasonal thermocline, in the intermediate layer, the water temperature is 6-8° C, the salinity 18-20 ppt, and the oxygen levels are reduced (0.2-0.4 mg/l). In winter, the seasonal thermocline disappears and the two layers become mixed. The temperature of this mixed layer in winter is 6-8° C. This layer is separated from the lower layer by a chemocline which is located at depths ranging between 30 m in cyclonic gyres to 180 m in anticyclonic gyres. The lower layer, which is slightly warmer than the intermediate layer (9° C), makes up by far the greatest part of the volume of the Black Sea. It is divided at the chemocline into an upper, very thin layer of oxygen-poor waters in which oxygen and hydrogen sulphide co-exist and the remainder of the lower layer that contains no free oxygen and in which no aerobic organisms can live (Rass, 1965; Sorokin, 1983; Vinogradov, Sapozhnikov and Shushkina, 1992).

4.2 Alteration of the Planktonic Community in the Black Sea

After the *Mnemiopsis* invasion, the structure of the planktonic communities in the open parts of the Sea significantly changed. The general abundance of subsurface mezoplankton declined 2-2.5 times or more on average, compared with the previous period. The biomass of some species decreased 3-10 times or more. The biomass of zooplankton, which inhabits the intermediate cold layer, such as the *Calanus euxinus* in 1991 (late summer to early fall), decreased 2.5 times on average compared with late summer-early fall 1989, and in late summer-early fall, 1992 - 3.5 times (Vinogradov *et al.*, 1992, Shushkina and Vinogradov 1991). In 1994 the annual average biomass of crustacean zooplankton in the upper mixed layer was 6 - 15 mg m^{-3}, which was about 3 times less than in 1960-74, and 5 times less than in 1993 (Studenikina *et al.*, in preparation).

The pronounced impact of *Mnemiopsis* upon the planktonic communities was recorded for all of the species on which it preys: small copepods *(Paracalanus, Acartia, Oithona, Pseudocalanus,* the Cladocera *(Penilla),* the larvae of benthic animals, the appendicularia which dwell in the upper mixed layer of the sea, and *Parasagitta setosa, Calanus euxinus* and *Pseudocalanus elongatus* which dwell in water below the thermocline.

After the start of the *Mnemiopsis* outbreak in 1987-88 (Table 2), the seasonal dynamics of their population numbers and density became strongly linked to their grazing abilities. In the Black Sea inshore waters, *Mnemiopsis* has a wide food spectrum from fish to molluscan larvae and cladocerans (Tsikhon-Lukanina *et al.*, 1992). The density of zooplankton was generally low in winter all over the Black Sea. They began to reproduce, grow and increase their biomass only in the early spring when the seasonal thermocline was formed. At the same time, benthic animal larvae (mostly of bivalves) appeared. The total biomass of zooplankton which could become prey for *Mnemiopsis* rose rapidly. The quantity of *Mnemiopsis, Pleurobrachia* and *Aurelia* concurrently started to increase. The pressure of carnivorous ctenophores soon led to a clearance of zooplankton biomass in some areas by an order of magnitude. In summer the quantity of zooplankton accessible as prey for *Mnemiopsis* dropped down to its winter low level. This substantial decrease in food concentration caused a subsequent decline of the *Mnemiopsis* population by autumn. The autumn resumption of feeding pressure caused an increase in biomass of consumed plankton, except in the southeastern region. The *Mnemiopsis* biomass in this warm area where the autumn processes start later, stayed constant from August to November, in 1989, 1991 and 1992 (Vinogradov *et al.*, 1992) (Fig.12).

A most pronounced impact of *Mnemiopsis* predation pressure was reflected in the seasonal dynamics of small Copepods - potential prey of *Mnemiopsis* and on *Sagitta setosa* populations (Vinogradov and Shushkina, 1992). Concerning *Sagitta,* the early spring rise in its biomass relates to a rapid growth of its population consisting of large, mature individuals (Fig.12). The death of the large-sized individuals of *Sagitta* after spawning, and the grazing of juvenile *Sagitta* by *Mnemiopsis* resulted in a sharp reduction of its population. In contrast to other small opportunistic zooplankton, the density of the *Sagitta* population did not increase during the autumn decrease of the *Mnemiopsis* predator (Fig.13).

The seasonal dynamics of the deep dwelling population of the Black Sea calanoid, *Calanus euxinus,* which is living below the thermocline down to the boundary layer of the main pycnocline, has specific features relating to its reproductive biology (Fig.14). Its main population, living in the open sea, is replenished from the shallow shelf where reproduction proceeds. Reproduction mainly proceeds in the NE part of the Black Sea during late winter. (Vinogradov *et al.,* 1992). The seasonal cycle of this species is determined both by the temporal and spacial redistribution of its population, and especially of its juveniles. In the open sea regions the population of *Calanus euxinus* is dominated by copepodites. Its seasonal dynamics appear to be rather similar in the open sea regions which were studied. In winter, the biomass of *Calanus euxinus* is low, as in other components of meso- and macroplankton. Later, numbers increase, due to the movement away from the shoals of the quickly developing juveniles. In the open sea, numbers of nauplii and early *Calanus* copepodites were large in February-March, as well as over the seasons. Maximum *Calanus* concentrations were observed in March-April and amounted to 4.5-8 m^{-2}. They decreased gradually then until November to values lower than at the beginning of the year. An increase in biomass took place only in the western gyre and might be occasional. The *Calanus* biomass declined during the whole spring to autumn period, primarily due to the grazing impact of *Mnemiopsis.* The grazing impact of *Calanus* was recorded in shallow waters off Anapa in winter when their populations came there for breeding (P. Sorokin, pers. comm.).

During the last few years, the biomass of small, mostly subsurface, mesozooplankton potentially accessible to grazing by *Mnemiopsis* has undergone fundamental changes. In 1989 the abundance of mesozooplankton declined an average of 2-2.5 times compared with the period before the invasion. The biomass of some species and groups decreased at least 3 to 10 times (Fig.14). The zooplankton species permanently living in the upper layer, which is also the food for *Mnemiopsis leidyi,* as well as those undergoing vertical migration, appear to be easily accessible to this predator. However, the species which remain in the deep water layer most of the time *(e.g. C. euxinus, P. elongatus)* are biotopically isolated from *Mnemiopsis leidyi* and are therefore less exposed to its feeding pressure (Vinogradov *et al.*, 1992).

After the *Mnemiopsis* invasion, the structure of planktonic communities in the Black Sea was significantly transformed. The decrease in biomass of zooplankton which inhabits the intermediate cold layer continued in 1990-1992. In the summer of 1991, its biomass was three times lower than in 1989 (Vinogradov *et al.*, 1992).

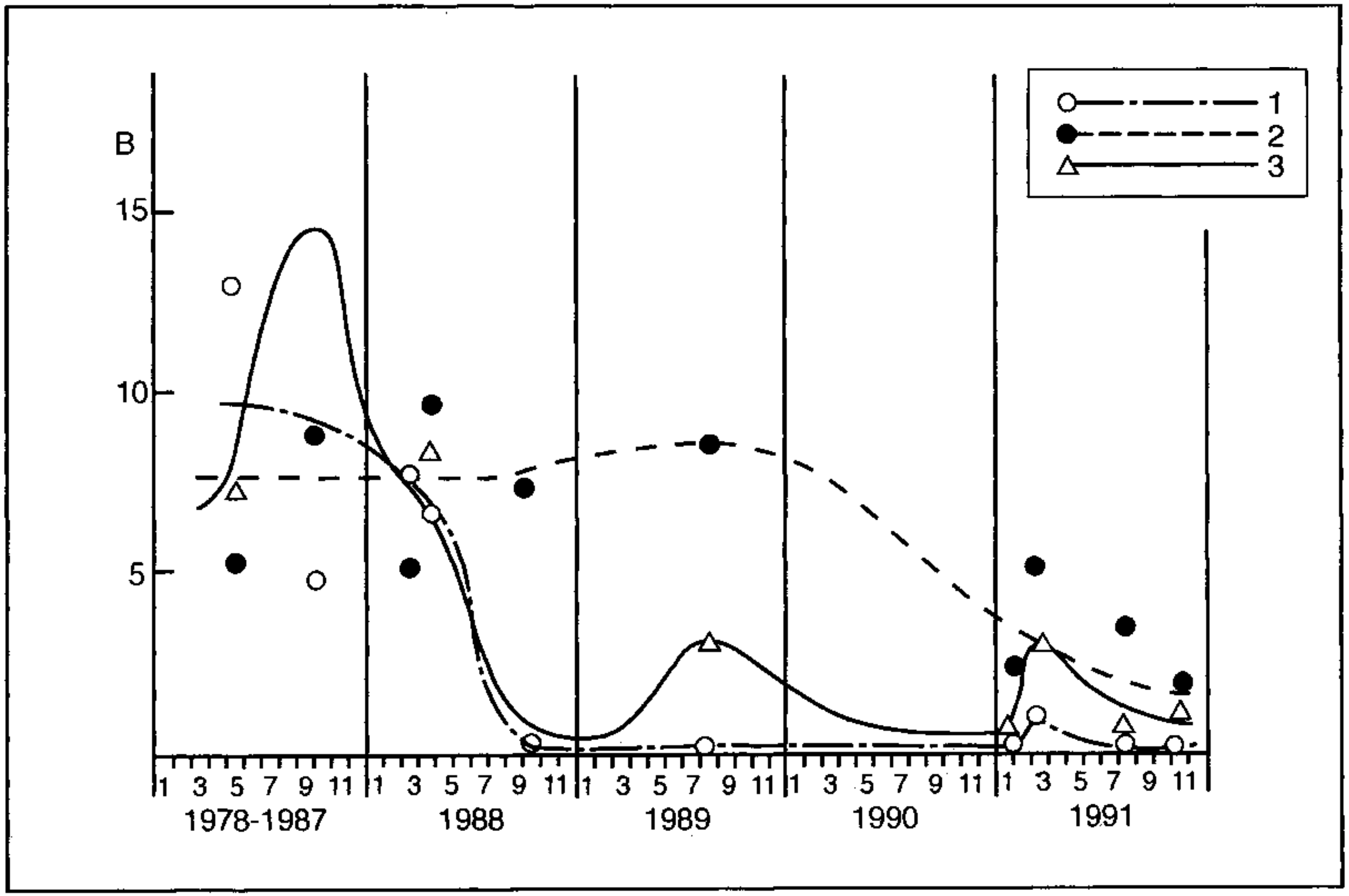


Figure 12: Trends in long-term changes of biomass (g m^{-2}) of some components of the open Black Sea zooplankton during 1978-1991; designators: 1- *Sagitta*; 2 - *Calanus euxinus*; 3 - potential prey zooplankton for *Mnemiopsis* and pelagic fish. After Vinogradov, 1992.

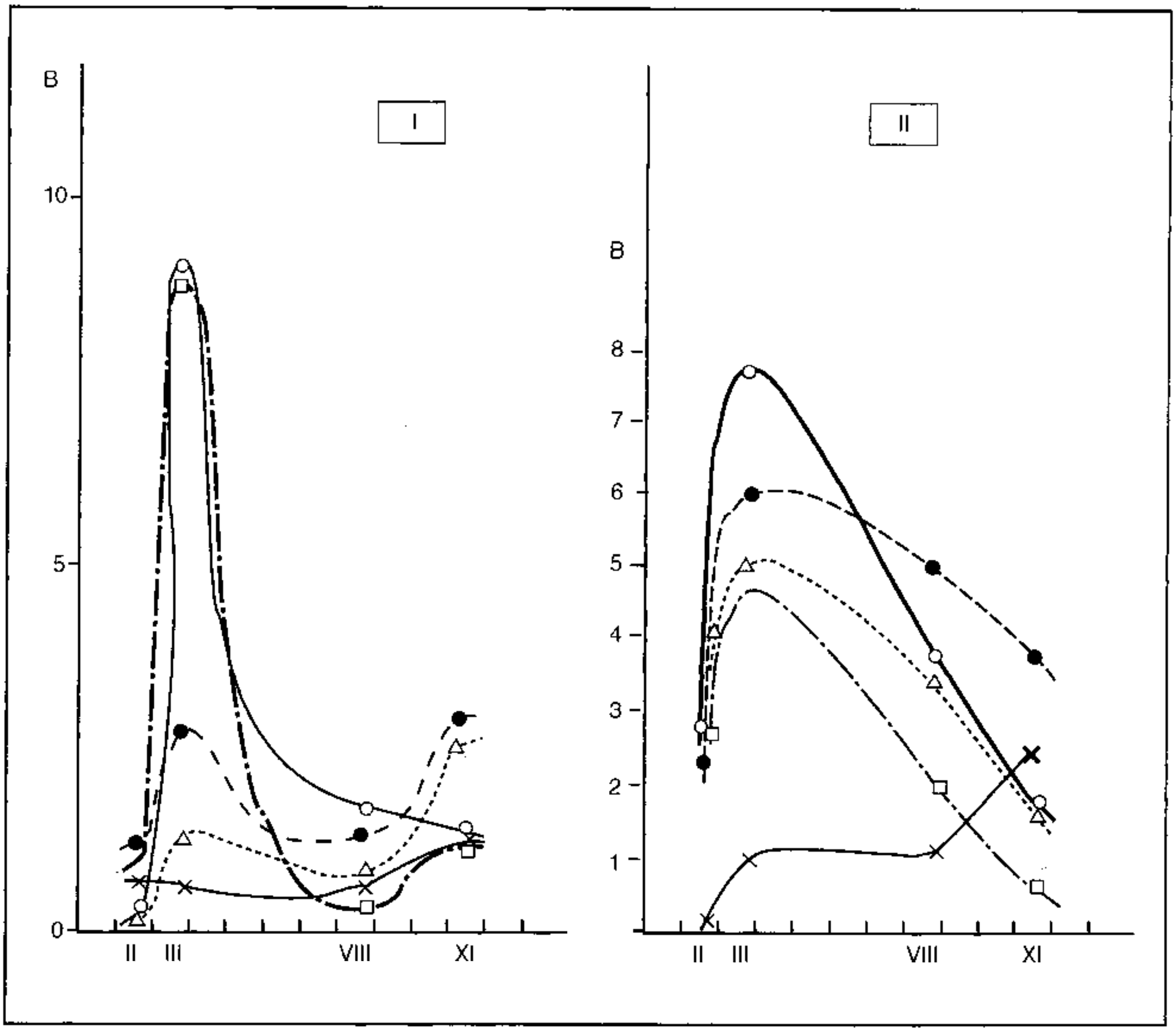
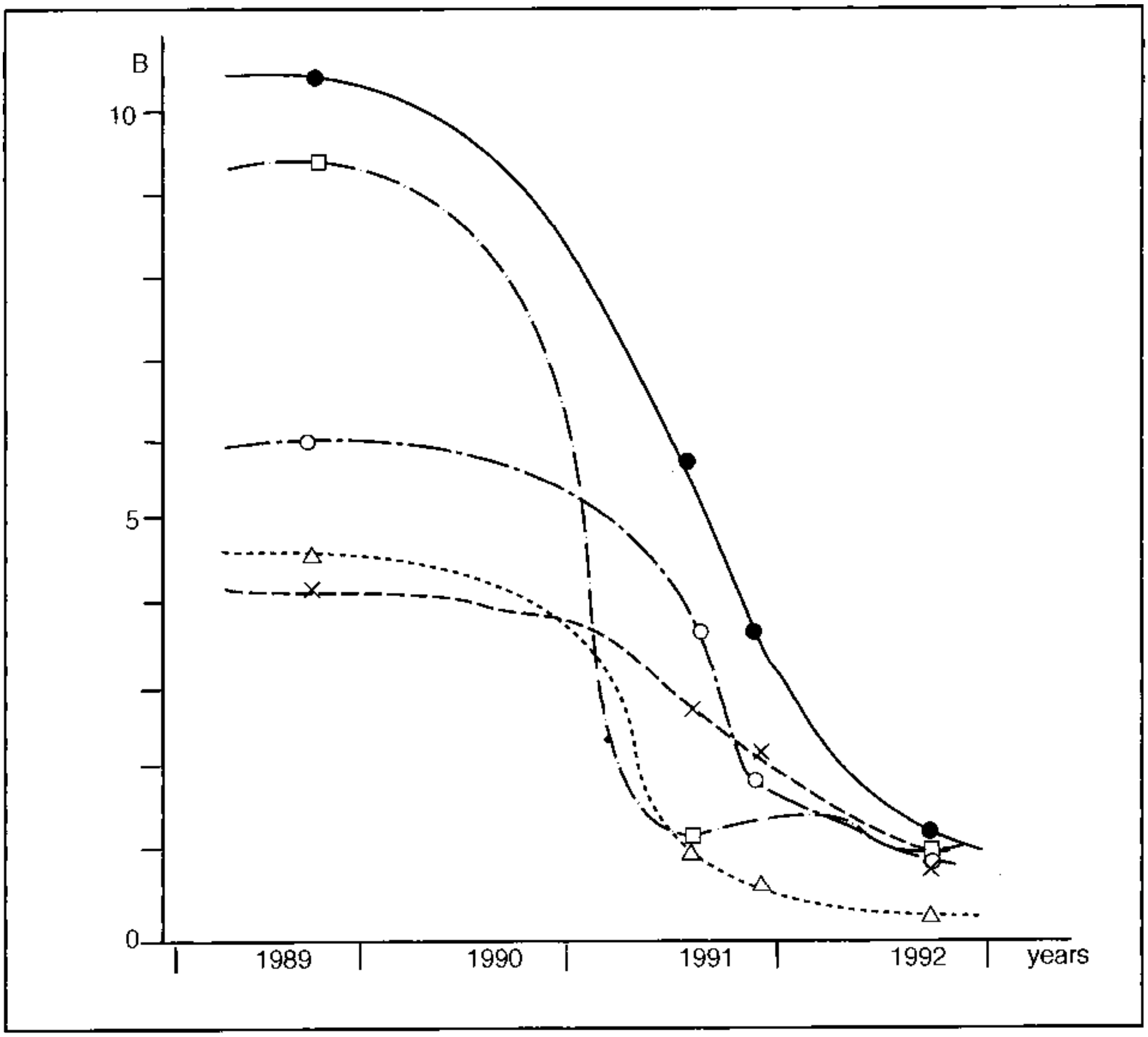


Figure 13: Seasonal dynamics of zooplankton biomass (g m^{-2}) as food for *Mnemiopsis*. I - Small zooplankton, II - *Calanus euxinus*; for other designation see legend to Fig. 1. After Vinogradov 1992.



Calanus euxinus

Figure 14: Trends of change in the biomass (g m^{-2}) of *Calanus euxinus* (for designations - see Fig. 1). After Vinogradov and Shushkina, 1992.

During the first period of its presence in the Black Sea, *Mnemiopsis* was rather strictly associated with the upper mixed layer above the thermocline. Assemblages of individuals were often found immediately under the surface. However, large ctenophores were observed beneath the thermocline layer, in autumn 1989, from the submersible "Osmotr". The spring observations of 1991 from the submersible "Argus" also showed the regular penetration of large quantities of ctenophores under the thermocline and down to the upper boundary of the pycnocline. During the summers of 1991 and 1992, in contrast to 1989, only a few individuals were encountered in the surface layer, and they concentrated near and within the thermocline. The whole population inhabited the thermocline layer, descending down to the boundary of the pycnocline. Under the thermocline the ctenophores probably started to feed on *Calanus*, migrating in the night from the deep water layer of its concentration. Such a strong feeding pressure apparently led to a reduction of the *Calanus* population (Fig.14). This reduction was predicted despite the copepod's irregular "cloud-wise" spatial distribution which hampers estimating its population numbers. A definite decreasing trend was recorded, starting in Spring 1991.

The appearance of large-sized ctenophores *Mnemiopsis* in the Black Sea waters able to consume high amounts of zooplankton, certainly represents one of the factors contributing to the alteration of the zooplanktonic communities during recent years when the mezoplankton biomass was significantly changed. In 1990 and 1991, the biomass of many species and groups were three to five times lower than in 1987. The species structure of planktonic communities was transformed. It seems that the effect of *Mnemiopsis* was the main cause of these variations. While the biomass of small prey zooplankton of *Mnemiopsis* became four times lower, the concentration of zooplankton organisms not consumed by *Mnemiopsis, Pleurobrachia pileus* in particular, remained at the same level. Owing to its highly significant effect on the stock and production of prey zooplankton, *Mnemiopsis* acts as a serious trophic rival of food plankton-eating fish and causes the reduction of their stock.

The impact of the *Mnemiopsis* outbreak upon the ecosystem is also shown by accumulation of large amounts of its biomass settling down to the anoxic zone during periods of its mortality and thus fuelling the H_2S production. The impact is due in part to the mucus which is shed in large quantities by the comb jellies. There is some evidence that this mucus is toxic to microplankton (Sorokin, pers. comm.). Ctenophore mucus has been observed in the Marmara Sea during its bloom in 1992, in the water column down to 300 m depth (Sorokin, pers. comm.).

4.3 Present State of Zooplankton in Romanian Black Sea Waters.

An analysis of the composition and evolution of zooplankton communities in coastal waters off Romania during the last decade could reflect the difference in dynamics of the open sea and the coastal zooplankton during the *Mnemiopsis* invasion. The mean biomass of total zooplankton increased from 1986 to 1989 due to some "blooms" of *Noctiluca*, especially during the summer. Forage zooplankton has continually decreased, being grazed by ctenophores.

The zooplankton communities in Romanian waters were drastically reduced and transformed particularly during the *Mnemiopsis* invasion in 1988-89. Their densities were extremely low both in spring and summer time during this period. The mean zooplankton biomass (including *Noctiluca*) in August 1988 was five times less than during the same month a few years previously. The share of *Noctiluca* in total plankton from normal 40 per cent rose during the ctenophore bloom up to 98 per cent , while the combined biomass of the food zooplankton with high trophic value, such as copepods, cladocerans, mezoplanktors, comprised only 2 per cent of the total biomass. The result was a large decrease in abundance of planktivorous fish.

4.4 Present State of Zooplankton in Bulgarian Black Sea Waters.

The outbreak of the comb jelly in 1988-89 resulted in a pronounced depletion of zooplankton biomass in Bulgarian coastal waters. In August 1989 zooplankton attained only 30 per cent of its density recorded in 1986 before this outbreak began. Between 1990-1991, a significant part of this depleted zooplankton in summer was represented by cladocerans which have a short reproduction period, while the copepods were practically absent, especially when the density of *Mnemiopsis* was high (Konsulov, 1989).

5 Impact on Fisheries

5.1 Impact of *Mnemiopsis* on Black Sea Fisheries

5.1.1 Conclusions of the General Fisheries Council for the Mediterranean (GFCM) Consultation on Black Sea Fisheries, Ankara, February 1993 (FAO Rep. 495)

The Consultation agreed on a wide range of questions relating to assessment and management of fish stocks, coastal zone management, research priorities, and others. The two main recommendations are given in Appendix D of the GFCM report. A "Working Group on Priorities" met during the GFCM Consultation, and highlighted two key recommendations for future action, essential to Black Sea Fisheries reconstruction:

The need for a new Black Sea Fisheries Convention and Commission with full membership of all coastal States.

This first recommendation was recognized as a precursor to coordinated action in jointly assessing fishery resources - arriving at common databases and regulations, setting up a common registry of experts, and establishing agreements on measures to take to restore a productive ecosystem in support of fisheries. Such a Commission is a necessary precursor to some coordinated control of catches and access to the resources.

Mnemiopsis control measures.

The second major recommendation related to control of *Mnemiopsis* (see Annex 2).

5.1.2 General Considerations

The *Mnemiopsis'* introduction to the Black Sea and the explosion of its population during and after 1988, was the main subject of the GFCM Second Consultation on Stock Assessment in the Black Sea (FAO Fisheries Report 495). The FAO report includes the proceedings and papers presented in Ankara, Turkey, 15-19 February 1993, which can be referred to for details.

Three main impacts of *Mnemiopsis* on the fisheries were identified: (a) predation on fish eggs and larvae (GFCM; Annex 3; Tsikhon-Lukanina *et al.*, 1993); (b) feeding on larvae and adult fish food, thus causing starvation (Zaika, 1993; GFCM 1993; Volovik *et al.*, 1991);

(c) further accelerating of ongoing ecological change presently being experienced due to eutrophication (for example, direct environmental impacts on the pelagic and benthic systems (anoxia) due to massive precipitation of mucus and dead ctenophores to the bottom on the shallow shelf).

The first two impacts are considered to be most important, though it is not fully clear as yet whether (a) or (b) is the key factor. The evidence from the low condition factor of anchovies in the early 1990s, and the broad consensus of the GFCM meeting, suggest that feeding conditions for adult anchovy have been affected by high *Mnemiopsis* predation on zooplankton.

Although ctenophore predation may have affected stock levels of a number of commercial species, the key impacts have been on Azov Sea kilka, and anchovy stocks in the Black and Azov Seas.

5.1.3 Impact of *Mnemiopsis* on Fish Catches

The collapse of the pelagic fishery in the Black and Azov Seas had grave consequences for the economic and social conditions of fishermen and the fishery industry of the respective coastal countries. Before the outbreak, the catch of former USSR States reached 250,000 tons; now they are about 30,000 tons. Turkish catches before and after the collapse were of a similar order of magnitude (GFCM 1993 - Annex IX). Fishing vessels are for sale in many countries, and fishermen are abandoning their profession. Therefore, the organization of international control of the use of Black Sea resources and of investments in the fishery industry is vital and urgent.

It could be supposed that the fishery suffers not only from the anthropogenic impacts (pollution, overfishing, introduced *Mnemiopsis*) but possibly also from climatic changes. The long-term fluctuations of the fish stocks of exploited species have taken place concurrently with changes of the taxonomic composition of the catch. From 1940 to 1960, the catch was dominated by pelagic plankton feeders, anchovy and horse mackerel, with some additional larger predators. In the catch from 1960 to 1970, the large predators (horse mackerel, bonito, mackerel, bluefish) were abundant. In the early 1990's, up to 95% of the catch was composed of the pelagic plankton-feeders, anchovy, sprat and horse mackerel. Thus the catchable stock of fish has been reduced in biodiversity, resulting in a possible greater vulnerability of the fishery to external impacts (Caddy and Griffiths, 1990; Serobaba, in preparation).

The total catch of all coastal countries around the Black Sea increased significantly over several decades, until the collapse in 1989. The peaks of the catch in CIS countries occurred in the late '70s-'80s, then stabilized. In contrast, Turkish landings continued to rise in the 1980s to become dominant. After 1988, the total Black Sea catch went down sharply as a result of the *Mnemiopsis* invasion (GFCM, 1993). The total fish stock before 1988-1989 was estimated at 3.5-4 million tons, of which the anchovy, sprat and horse mackerel made up about 2-3 million tons, include 1.5 million tons in the CIS area (Table 4.).

The same situation existed with fish stocks and catches near the Turkish coast. Thus, after 1981, the highest annual fish catches among all Black Sea (as well as all Mediterranean) countries have been achieved in Turkey (Fig.15). 60-72% of the total fish production of Turkey consisted of Black Sea anchovy between 1980 and 1988. After 1988, the Turkish Black Sea anchovy and consequently the total Black Sea catch decreased sharply. Acoustical studies showed that the total stock of anchovy in the Turkish Exclusive Economic Zone between 1989 and 1992 ranged from only 150 to 360 thousand tons (Table 6). In the same period, 22-44% of fish were estimated to be caught.

The main targets of fishing in the CIS countries now are the anchovies and sprat. The fluctuations in catches during the last decade are shown in Tables 4 and 5.

The anchovy catches decreased drastically after 1988, largely as a consequence of the *Mnemiopsis* invasion (GFCM, 1993). Sprat catches also decreased, but later - after 1990 - as a consequence of the decrease in fishing efforts by CIS countries. At this time, the fishery faced serious socio-economic problems, notably, shortages of fuel for fishing boats. The stock of sprat is now estimated to be high. Thus, in the CIS zone, the stock of sprat is estimated to be about 500-700 thousand tons (Serobaba, in preparation, pers. comm.).

Simultaneously, the harvestable stocks of horse mackerel, anchovies and red mullet declined severely, suffering from the *Mnemiopsis* invasion which decreased the concentration of available zooplankton . Some improvements in 1992-1993 could be deduced from the Turkish fish landing data for those years. Data on catches of the Black Sea anchovy by traps along Romanian and Ukrainian coasts (the north-western part of the Sea) show a trend of increasing anchovy catches during the summer season of 1993-1994 (Serobaba and Nicolaev, pers. observ). Increasing anchovy catches, from 70 to 100 thousand tons, were also occurring along the Turkish coast (Kideys, 1994).

An estimation of anchovy stocks by Ukrainian scientists showed that their numbers have increased now, but remain 2-3 times less than during the period before the *Mnemiopsis* outbreak.

Horse mackerel stocks are currently in decline. Trap catches by Ukrainian fishermen show some quantities of fry and young fishes (age 1+). However, forecasts are not good for an increase of horse mackerel stocks in the coastal zone of Romania, Ukraine and Russia in the near future (Serobaba, in press; Nicolaev, Volovik, pers. observ.). In 1993-1994, the Ukrainian fishery landed a total of about 22-40 thousand tons of fish from the Azov-Black Sea region: approximately the same catch was obtained in 1992, but this was several times lower than catches between 1980-88 (Serobaba, in preparation; Volovik *et al.*, 1993). The same situation was noted in the Romanian fishery where catches of commercial fishes were approximately 3.3-4.0 thousand tons in 1993-1994, which is 4 times less than catches in previous decades (Nicolaev, pers. observ.) Fisheries in Bulgaria have failed almost entirely in recent years, too (Konsulov, pers. observ.).

The catch declines described above were a consequence not only of the *Mnemiopsis* impact but also a result of the economic and social crisis in CIS nations. In such a situation, careful monitoring of international co-operation has to be established.

Table 4: Standing stocks of pelagic fish in the CIS part of the Black Sea (oscillations during the last 2-3 decades) (Source: unpublished data of the Yug NIRO)

Fish	stock, 10^3 tons
Engraulis (anchovy)	130-600
Sprattus (sprat)	100-1300
Trachurus (horse mackerel)	37-132

Table 5: Catches of anchovies, sprat and mackerel in CIS countries, X10^3 tons

	Years										
Species	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Anchovy	204.1	110.2	191.4	66.2	228.2	64.4	28.9	5.8	10.0	0.2*	0.4*
Sprat	24.6	28.9	43.1	45.3	54.2	89.0	48.0	15.0	14.8	12.0	11.1
Horse mackerel	4.0	35.3	1.6	3.5	0.4	0.3	0.1	0.0	1.0	0.0	0.0

* Catches of the Black Sea anchovy are only by coastal pounds nets in the north-western part of the Black Sea. Traditional fish catches by fleet in the eastern part of the sea were absent. No data on the Georgian fishery region.

(Source: unpublished data of the YugNIRO).

Table 6: Comparison of anchovy biomass estimated from acoustical surveys and catch of anchovy for the respective year in the Turkish Exclusive Economic Zone (Bingel *et al.*, 1993).

Fishing season	Corrected biomass (x10^3 tons)	Catch (x10^3 tons)	Catch/Biomass (as percentage)
1989/90	310	97	31
1989/90	230	97	35
1990/91	150	66	44
1991/92	360	79	22

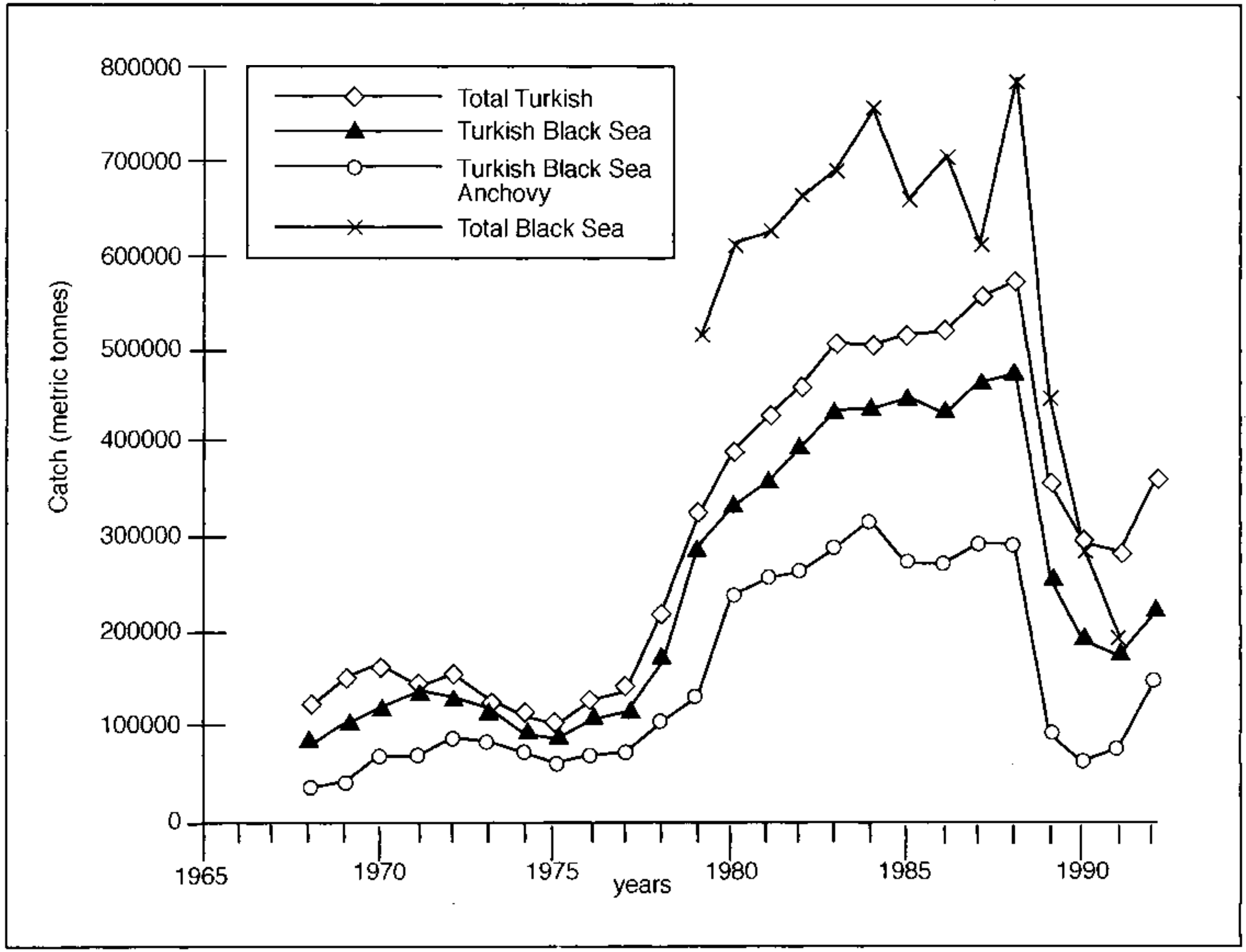


Figure 15: Importance of of anchovy fishing in Turkish and Black Sea fisheries (Sources, SIS, 1968-1991 and GFCM, 1993)

5.1.4 Events in the Black Sea Prior to 1988

Since the end of the Second World War, there have been a number of dramatic changes in the Black Sea ecosystem that have 'set the scene' for the invasion by *Mnemiopsis leidyi* of the pelagic biome. Among these are:

- the impacts of intensive industrial fishing (e.g. Ivanov and Beverton 1985);
- water extraction and barrages affecting estuarine salinities; and
- eutrophication of the marine ecosystem, especially from incoming riverine nutrients (Mee 1992).

Many changes have resulted from a combination of these factors (Caddy and Griffith 1990; Caddy 1993; Zaitsev 1993; G.F.C.M. 1993). These include:

- depletion of top predators (bonito, bluefish, turbot, marine mammals) reduced predatory pressure on the small pelagic fish biomass; however, this also may have resulted from pollution impacts on spawning and migration;
- decline in demersal fish, benthos and macrophytes occurred as a result of nutrient overloading. The earliest stages of this process, however, resulted in increases in biomass of small pelagic fish (Ivanov and Beverton 1985) and led to *Aurelia* outbreaks in the late 1970s; and
- degraded water quality and reduced flow of river inputs, especially to the Northern Black and Azov Seas basins, have affected anadromous fish migration, and led to increases in salinity of the Azov Sea.

Thus, the invasion of *Mnemiopsis leidyi* of the pelagic biome in the mid- to late 1980s encountered a high standing stock of pelagic zooplankton, whereas a heavily exploited small pelagic fish population, with annual exploitation rates of up to 50 per cent or more, competed with *Aurelia* for the role of dominant primary carnivore. Such high exploitation rates of traditionally important zooplanktivores (anchovy, horse mackerel, kilka, etc.) may have acted jointly, perhaps synergistically, with eutrophication to open up an ecological niche for the comb jelly predator in the pelagic ecosystem of the Black Sea. This role was first filled by *Aurelia* and then by *Mnemiopsis*. A summary of the key events is described by Zaitsev (1993).

In the Romanian fishery, the decrease of zooplankton biomass has been correlated with a spectacular reduction of the catches of fish feeding on plankton. The anchovy production decreased from 6,354 tons in 1984 to 1,946 tons in 1988, 66 tons in 1989, only 5 tons in 1990 and 50 tons in 1994. The production of sprat was 8,912 tons in 1989, 3,198 tons in 1990 and 720 tons in 1991. The production of horse mackerel was reduced from 1,459 tons in 1988, to 165 tons in 1990 and insignificant quantities in 1991-1994.

5.1.5 Events in the Black Sea Since 1988

The *Mnemiopsis* invasion had a grave impact on the Black Sea fishery (FAO 1993). After 1988, the remaining commercially important pelagic fish stocks drastically decreased. In addition, the recruitment of harvestable generations of pelagic fish (anchovies and horse mackerel) was reduced to negligible levels. These events were a consequence, at least in part, of the direct grazing impact of the new predatory intruder, which competed with these fishes for food and ate their eggs and larvae. The drop in fish catch by the CIS countries was also related to the decrease in fishing efforts on this species, aggravated by the deterioration of the socio-economic situation in CIS countries. Thus, a general decrease in the volume of fish landings after 1988-1990 resulted not only from the invasion of the basin by *Mnemiopsis*, but also by the socio-economic crisis in the former communist Black Sea countries.

The stock of small pelagic fish prior to 1989 was believed to be of the order of 3 million tons for the Black Sea basin as a whole, of which anchovy, sprat and horse mackerel were the key components,and kilka in the Azov Sea. With respect to anchovy, stock sizes and catches dropped dramatically after 1989. A survey by the former USSR in 1990-91 found an overwintering stock of only 30,000 t in very poor physiological condition (GFCM 1993). Evidently, competition for food resources by *Mnemiopsis* was a major contributor to this situation. Poor recruitment in this and subsequent years, and movement to 'premature' spawning of 0+ - 1+ year-classes, may have occurred in response to this in later years, There may also have been a change in main spawning location. Niermann *et al.* (1994) indicated that there has been a shift in the spawning area of anchovy from the north-northwestern Black Sea to the south-southern region. Some stock recovery may be occurring now, but the current stock size is below that of the 1970s, when stock sizes apparently increased as a result of nutrient enrichment (GFCM 1993). Kilka stocks for the Azov Sea dropped after 1989 from a high of 450,000 t - 600,000 t biomass and have stayed low since, as have stocks of horse mackerel.

The situation for sprat is somewhat different. After an increase in biomass to approximately one million tons ascribed to nutrient enrichment in the 1970s (Ivanov and Beverton, 1985), the stock may have dropped to around 600,000-700,000 t. This stock is largely protected from *Mnemiopsis* impacts on its food, *Calanus euxinus*, which is found in the cold intermediate layer. However, there now are concerns that *Mnemiopsis* may be moving deeper in the water column to harvest this previously unpreyed-upon species, with likely negative consequences on the stocks of sprat. Sprat remain at this time (circa 1994) as one of the most commercially important pelagic fisheries in the region.

5.2 Impact of *Mnemiopsis* on the Azov Sea Fisheries

The ctenophore *Mnemiopsis* invasion into the Sea of Azov in 1988-89 seriously damaged its ecosystem (Volovik *et al.*, 1991). Due to the grazing pressure of the intruder, there was a drastic change in the seasonal dynamics and abundance of holoplanktonic and meroplanktonic zooplankton. Instead of two maxima of zooplankton in the spring (the minor) and the summer (the main), only the spring maximum remained. The main maximum in summer disappeared due to the grazing pressure of *Mnemiopsis*. Therefore the migrating stock of kilka and anchovies that appeared at the time when the concentration of zooplankton was decreased by *Mnemiopsis leidyi* experienced a lack of food (Studenikina *et al.*, 1991). A pronounced decrease (approx. 2-10 times) of meroplankton in summer also occurred, showing the grazing impact of *Mnemiopsis* upon the larvae of benthic animals and thus upon the benthos. The subsequent decrease of the zoobenthos biomass by about 30% was estimated (Volovik *et al.*, 1993).

The abundant stocks of zooplankton in the Azov Sea had been originally used by the anchovies and kilka, which attained a total biomass up to 1.7 million tons and production of 1.8 million tons. With its introduction by late 1988, the comb jelly became a main competitor for food stocks for small pelagic fishes. The predation of *Mnemiopsis* on their spawn and larvae also could be expected. In areas with a high ctenophore density, the eggs and larvae were absent. In areas modestly infected by this outbreak, their density was reduced markedly. The deficiency of available food resulted in the poor fat accumulation by anchovy and kilka by the end of the season. The fish therefore lacked sufficient energy for successful winter migration and for the creation of gametes. All of these events related to the new predator resulted in a drastic decrease of fish production - of kilka 4-5 times and of anchovy, over 10 times. There was a decline in the biomass of both populations and the catch in about the same proportions , which caused large-scale damage to the fishery. The annual losses of the fish catch attributed to the *Mnemiopsis* plague were calculated to be approximately 30-40 million U.S. dollars a year (Volovik *et al.*, 1993; Volovik *et al.*, in preparation).

5.3 Other Ecosystem Impacts of *Mnemiopsis*

The process of assessing ecosystem risks related to the introduction of exotic or alien species can be broken down into two parts: (1) risk identification; and (2) comparison of risk to expected effects in natural systems. Some of the topics to be included in this process could include a consideration of the fate and effects of decaying *Mnemiopsis* biomass and the extent to which energy and nutrients incorporated into the *Mnemiopsis* biomass become processed by the microbial loop in the pelagic zone or sink down through the chemocline. The impact of *Mnemiopsis* on the zoobenthos also might be mainly indirect (e.g., feeding on larvae of benthic animals, and competition for common food resources - zooplankton -with benthic filter feeders).

6 Monitoring and Modelling the Role of the Ctenophore *Mnemiopsis* leidyi in the Black Sea Region

6.1 Monitoring Strategy and Methodology for Determining the Population Dynamics of *Mnemiopsis* and its Impact on Pelagic Communities

Monitoring of the Black Sea ecosystem to describe accurately the *Mnemiopsis* problem should be continued. Its objectives should be the collection of data on the change of environmental conditions and the structure of biological communities in relation to *Mnemiopsis* density and development patterns. The monitoring should be based on uniform methodologies and cover shallow waters and open sea areas as well. The main goal of the monitoring would be a description of the efficiency of the *Mnemiopsis* population control strategy, selected to reduce the invader's populations, and the verification of models prepared to predict the abundance of *Mnemiopsis* and its impact on biota and on fisheries catches.

Monitoring guidelines are described in Annex 4.

6.2 Modelling the Role of *Mnemiopsis leidyi* in the Black Sea Ecosystem

There are at least three recent models of the marine ecosystem of the Black Sea. They include one of M. Vinogradov; an attempt at comprehensive modelling of plankton dynamics (Lebedeva and Shushkina 1994); and a similar whole-system model for the Azov Sea, described by Volovik *et al.* (1993) and presented at a 1993 ICES meeting. A much simpler model considering possible impacts of *Mnemiopsis* on fisheries was presented at the 1993 GFLM Consultation (Christensen and Caddy 1993).

The Russian Research Institute of the Azov Sea is developing a model of *Mnemiopsis* population dynamics, as one of the main components of a marine ecosystem model. The main goals of this model are descriptions of ctenophore population dynamics related to changes in the main components of the marine ecosystem. The model will consider hydrological conditions (ice situation, temperature regime, water currents and water discharges between the eight regions of the Azov Sea; between the Azov and Black Seas via the Kerch Strait according to meteorological conditions; hydrochemical conditions (dynamics of biogenic elements and different kinds of pollution); hydrobiological conditions (phyto-, zooplankton and zoobenthos); and characteristics of fishery species communities (dynamics of populations of the main commercial fishes, especially anchovy and kilka).

At present (circa 3/95), two blocks of this model are ready. They describe hydrological situations and ctenophore population dynamics (invasion and distribution, feeding, breeding, biomass and population composition during different seasons). Validation of this model has shown good predictions of the real situation. Additional units of the model dealing with the zooplankton community are being developed; they include population dynamics of the main representatives of the community (Volovik *et al.*, 1994).

The Christensen and Caddy (1993) application of the standard ECOPATH II model (Christensen and Pauly 1992) presents a very simplified box model of the Black Sea ecosystem, (a) with *Mnemiopsis* present, and (b) with both *Mnemiopsis* and *Beroe* present.

This model, despite its oversimplification, is 'user-friendly'; it has been applied to a wide variety of food webs globally, and it should be seen as a simple accounting system for food webs. The model can be run easily by scientists in the Black Sea, using improved data and assumptions. Output of the present version of the model suggests that *Mnemiopsis* would have strongly negative impacts on fish larvae, fish, zooplankton and *Aurelia*, but would enhance slightly the phytoplankton populations. The addition of *Beroe* is predicted to reduce the *Mnemiopsis* population significantly, with a slightly positive impact on fish, zooplankton and fisheries.

There have been two new initiatives of the Black Sea programme on modelling:

1) The COMSBLACK NATO Black Sea second phase will concentrate on modelling long-term and climatic changes, circulation dynamics, multi-scale biochemical processes, and phytoplankton, and may be extended to zooplankton dynamics.

2) The EROS 2000 proposal will model interaction and inputs between the river Danube and the NW Black Sea, as they relate to changes in river discharge and chemical/sediment inputs to the phyto- and zooplankton dynamics, possibly including *Mnemiopsis* dynamics, but not including fisheries.

These modelling exercises also could incorporate higher ecosystem components including both *Mnemiopsis* and pelagic fish.

There could be at least three types of Black Sea ecosystem models:

a) models describing the changes in the dynamics of the ecosystem after the introduction of *Mnemiopsis* and the long-term fluctuations of its population;

b) models describing the seasonal dynamics of development of whole planktonic communities and the energy flow within them, accounting for seasonal changes in taxonomic and trophic community structure, before and after the *Mnemiopsis* introduction; and

c) fate of the nutrients from the populations of *Mnemiopsis* in the water column.

Evidently, construction of the first type of model relies on having a model of the second type. Therefore the efforts in modelling should be concentrated around models of the second kind. An example of such a model was offered by Lebedeva and Shushkina (1994). The model was validated and verified and showed good correlation with observations made during one of the Shirshov Oceanology Institute cruises.

The model by Lebedeva and Shushkina (1993), developed at the Shirshov Institute of Oceanology, describes the seasonal dynamics of pelagic communities in the open Black Sea regions for the periods before and after the *Mnemiopsis* outbreak. The model concerns the seasonal dynamics of basic components of the pelagic community: phytoplankton, bacteria, protozoa, small zooplankton living in the upper mixed layer, plus *Mnemiopsis* and *Aurelia aurita*. The models were based upon the balance equations $P = CU^{-1} - R$ (where P = production, R = respiration, C = food ration and U^{-1} = rate of food assimilation). In the model the measured parameters of numbers and biomass of different components of the community (phytoplankton, bacteria, protozoa, mesoplankton, jellyfish *Aurelia*, and comb jellies *Pleurobrachia* and *Mnemiopsis*) were used. The model was validated successfully. It describes seasonal changes in the composition and development of pelagic communities in the Black Sea, before and after the *Mnemiopsis* invasion. The model was used for the computer experiments, offering the opportunity to evaluate the maximum grazing impact of *Mnemiopsis*, identifying the conditions under which the pelagic community still remains balanced and functionally active.

7 Control of Invasions

7.1 Perspectives on International Marine Biological Control Strategies

The field of control strategies for invasive pest species, with a history of several centuries on land, is in its infancy in marine ecosystems. In addition to the problem of opportunistic invaders in the Black Sea, there are growing interests around the world in undertaking research on the possibility of post-invasion control of introduced species. One important example is the establishment in 1994-95 of a new research bureau under the aegis of CSIRO, Australia. This bureau, entitled the "Centre for Research on Introduced Marine Pests" (CRIMP), has as one of its objectives the "development and testing of new control measures, including novel, ecological, physiological and genetic techniques for existing introduced pests" (CSIRO, 1994). CSIRO, with a history since 1926 of terrestrial biocontrol efforts, established CRIMP in response to several waves of marine invasions, including Japanese species of kelp (*Undaria pinnatifida*) and starfish (*Asterias amurensis*), and a Mediterranean polychaete fanworm (the sabellid *Sabella spallanzanii*). In contrast to the Australian Quarantine and Inspection Service (AQIS), which has responsibility for the prevention of introductions (pre-invasion control), CRIMP will have primary responsibility for doing research on post-invasion control.

7.2 Strategies for the Control of Invasions of Marine and Brackish Water Organisms

Strategies for the regulation and management of non-native species fall into three broad categories:

I Preventing the introduction of exotic species;
II Eradication or control of introduced species; and
III Prevention of further dispersal of the introduced species.

Strategies I and III are discussed elsewhere in this report. This section deals with strategy II, the eradication or control of an already-introduced species.

Table 7 presents an outline of the various strategies that might be used to control the population levels of an introduced species. Control attempts have had one or both of the following goals: (1) To eliminate a species, thus completely removing it from the ecosystem, or (2) to regulate the abundance of a species either throughout the range of its introduction or only within portions of its range of introduction in order to reduce its impact on the ecosystem. For all strategies, both the specificity and effectiveness of the methods that are used are important. A generally agreed-upon principle is that species management usually involves more than one strategy, an approach that is referred to in agricultural science as "integrated pest control."

The Group agreed that eradication of *Mnemiopsis* populations is unlikely, since the entire basin in both seas is too large. Therefore, methods of control should be directed toward controlling its abundance and patch dynamics. The six strategies listed in Table 7 were considered. The conclusion was reached that only Strategy VI (ecological control by species introduction or enhancement) has a realistic chance of success. The reasons for this statement are described below.

Strategy I **Mechanical Control**. Harvesting of *Mnemiopsis* for commercial purposes would fall into this category. The Black Sea basin is too vast and the growth rates of populations of *Mnemiopsis* are too high for such a procedure to be effective. Selective mechanical removal of planktonic gelatinous organisms is not possible at this time. Even in the case of benthic organisms, which are much easier to locate and remove, mechanical removal has had no success. Examples include the European crab, *Carcinus maenas*, in the State of Maine, U.S.A. in the 1950s; the Japanese seaweed, *Sargassum muticum*, in southern England in the 1970s; and the Atlantic snail, *Urosalpinx cinere*a, in England in the 1950s, all of which were not controlled successfully. The uniform lack of success of this method shows that it is not feasible as a control strategy.

Strategy II **Chemical Control**. It is unlikely that chemicals that would destroy only populations of *Mnemiopsis*, with no deleterious effect on fish populations, could be developed. Pesticides are likely to destroy not only the fish themselves, but their forage organisms, such as copepods and benthic and planktonic larval invertebrates. The success of agricultural pesticides is based on the fact that the physiologies of plants and insects are radically different. In fact, many agricultural pesticides are toxic to animals other than insects. In the case of marine organisms, we are often dealing with pests that have physiologies similar to those of the resources (fish, crustaceans and molluscs). Therefore, it is considered unlikely that a pesticide could be developed that specifically would destroy populations of *Mnemiopsis*, without the expenditure of large sums of money over a very long time period.

Another major problem with the use of pesticides in aquatic environments is that of dilution. On land, pesticides tend to stay in the same location as the crop, but in water pesticides are rapidly dispersed, so that much higher concentrations are required, with correspondingly greater environmental hazards. Further, since populations of *Mnemiopsis* are already extremely large in the Black Sea, and are capable of rapid reproduction, applications of pesticides would have only a transient effect on their population size. In addition, the ctenophores might rapidly develop resistance to them.

Strategy III **Physiological Control**. This approach would require considerable basic research, since no such compounds for ctenophores are presently known. This means the allocation of a lot of time and money. Furthermore, the dilution problems discussed under strategy II also apply to these chemicals.

Strategy IV **Genetic Control**. This approach would also require the investment of massive amounts of time and money devoted to basic research. In addition, since *Mnemiopsis leidyi* is a simultaneous hermaphrodite that is able to fertilize itself, the spread of unfavorable genes through the population would be unpredictable. The Working Group could see no prospects for the development of a genetic control strategy.

Strategy V **Ecological Control by Habitat Modification**. The type of habitat modification that might decrease populations of *Mnemiopsis leidyi* is unclear. An improvement of the Black Sea environment (i.e, the reduction of pollution) would not result necessarily in a decrease in *M. leidyi* populations, since massive blooms of this species were reported in relatively pristine and undisturbed environments in the Americas in the nineteenth century (Rang, 1829; Gould, 1841; Agassiz, 1865; Fewkes, 1881). Likewise, further degradation of the environment may not result in a decrease either, since *M. leidyi* occurs in relatively large numbers in polluted regions such as Biscayne Bay (Reeve and Baker, 1974), Tampa Bay (Harbison, pers. observ.), Galveston Bay (Pullen, 1960) and Buenos Aires (Ramirez, 1973). Thus, environmental amelioration, while desirable for numerous reasons, cannot be predicted with certainty to cause a decrease in populations of *M. leidyi*. In addition, habitat modification would require massive funding and decades to achieve.

Strategy VI **Ecological Control by Species Introduction or Enhancement of Endemic Species**. Based on the points raised above, the Working Group concluded that this strategy is the only feasible approach, given the constraints of limited time and financial resources. Many examples could be given where only the introduction of predators from the home range of the pest have served to control it. One of the best-known examples is that of the rabbit in Australia, which has only been controlled by introduced diseases and predators. The introduced predator does not always have to come from the home range. For example, introduced Pacific salmon have been notably successful in controlling levels of the nuisance species, the Atlantic shad *Alosa pseudoharengus*.

The major reason that the introduction of an exotic species into a new environment often results in its population explosion is because most or all of its natural predators, parasites and diseases are absent. Therefore, it is essential that the predators that inhabit the home range of the pest be investigated, since predators that have evolved in the same habitat as the pest will be best equipped to prey on it.

In highly diverse ecosystems that contain many species, indigenous predators may be able to adapt to the invader, and control its population density. However, in ecosystems with a low diversity of species, such predators may not be present. This was the case with the introduction of the rabbit in Australia, and it is also the case with the introduction of *Mnemiopsis leidyi* into the Black Sea. For example, the Black Sea contains only 150 species of fish (Svetovidov, 1964), while the adjacent Mediterranean contains 800 species of fish (Fischer, Bauchot and Schneider, 1987). Thus, even though populations of *M. leidyi* have now been established in the Mediterranean (Kideys and Niermann, 1994), it is expected that these populations will not have as deleterious effect on fish populations there, since there are probably enough indigenous predators in the Mediterranean that can control populations of the ctenophore. These Mediterranean predators have been unable to enter the Black Sea because of the great difference in its hydrological characteristics. The best places to look for predators that can establish themselves in the Black Sea are in those regions of the Americas that resemble it hydrologically.

7.3 Strategies for the Biological Control of the Invasion of *Mnemiopsis leidyi* in the Black Sea

In order to prevent further damage by *Mnemiopsis leidyi* to the pelagic ecosystem of the Black Sea, and to restore it to a commercially productive state, some method of control of *M. leidyi* populations must be developed. Control should have one or more of the following objectives:

(a) creation of new fishery resources. This would involve introduction of a new species that could feed on or outcompete *Mnemiopsis leidyi*;

(b) rehabilitation of pelagic fish stocks. This would involve promotion of a sustainable level of exploitation and the improvement of the Black Sea environment;

(c) development of alternative mariculture or fish farming facilities. This would protect juvenile and larval stages from predation in the natural environment. Fish farming of non-indigenous species that could not reproduce in the Black Sea might be advantageous; and

(d) restoration of pelagic fishery stocks to levels immediately before the *Mnemiopsis leidyi* outbreak in 1988. This objective might be achieved by introducing species that could reduce populations of *M. leidyi*.

A reduction in *Mnemiopsis leidyi* population levels is essential. The introduction and subsequent population explosion of *M. leidyi* has resulted from human activities, and it would be overly optimistic to expect it to correct itself without human intervention. Thus, control measures under human direction must be undertaken to reduce this population. The need for immediate action to reduce the intensity of *M. leidyi* blooms is emphasized by the fact that in 1994 levels of the ctenophore were almost as high as in the peak years of 1989 and 1990.

Table 7: Theoretical strategies for the control of invasions of marine and brackish-water organisms

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I. MECHANICAL CONTROL

Method usually does not extend beyond treatment area:

(a) Mechanical removal of individuals (rationale may include the harvesting of the species for use of some kind)

(b) Mechanical in-situ destruction of individuals (for all organisms, regenerative powers from pieces must be determined)

II. CHEMICAL CONTROL

Toxic chemical release, including the development of species-specific chemicals. Method may extend beyond treatment area, but may be limited, especially if the chemicals are of short life.

III. PHYSIOLOGICAL CONTROL (autocidal)

Method includes a chemical inhibitor or disrupter. Method may extend beyond treatment area, but may be limited, especially if the chemicals are of short life. Examples include metabolic interference (such as interference with feeding or locomotion) or life cycle interference.

IV. GENETIC CONTROL

Genetic engineering of introduced species to reduce environmental tolerances, fitness, etc.

V. ECOLOGICAL CONTROL BY HABITAT MODIFICATION (Environmental manipulation)

Environment is modified in some manner (physically or chemically) so that either:

(a) Target species is affected and/or;

(b) Biocontrol species is enhanced. This may include environmental amelioration (pollution reduction). Methods may have repercussions beyond treatment area.

VI. ECOLOGICAL CONTROL BY SPECIES INTRODUCTION OR ENHANCEMENT (Biocontrol)

Introduction of one or more exotic species or enhancement of one or more native species. Method has great potential to extend beyond treatment area. Exotic or native taxa include:

(a) Parasites and parasitic castrators;

(b) Parasitoids;

(c) Pathogens (disease agents);

(d) Predators for which host-level specificity must be determined;

(e) Competitors (not usually included under the definition of biocontrol).

Two strategies of biological control of *Mnemiopsis leidyi* are proposed:

1 An improvement of *Trachurus mediterraneus* (horse mackerel) stocks would most likely have beneficial consequences, as would the improvement of the stocks of other indigenous fishes that feed on *M. leidyi*. This could be achieved by a decrease in fishing effort, and a reduction of pollution in the Black Sea and adjacent waters. It is strongly recommended that this course of action be studied.

2 Introduction of organisms from the home range of *Mnemiopsis leidyi* or other areas. Such introductions can be divided into four types:

(a) Introduction of diseases specific to *Mnemiopsis leidyi*. No such diseases are presently known, and thus considerable time and funds would be required for basic research, followed by extensive testing. Since this is such a powerful tool for pest control, the Group recommends that such basic research be conducted.

(b) Introduction of parasites and parasitoids that could reduce the fecundity of the ctenophore. Of the parasites of ctenophores that are known, some may infect fish, with ctenophores as intermediate hosts (Yip, 1984). Since the introduction of such parasites could cause further damage to fish stocks, basic research in this area is recommended only reluctantly. If this course is chosen, all of the life stages of the chosen parasite should be identified, so that the possibility that it can infect indigenous species is excluded.

(c) Introduction of competitors to *Mnemiopsis leidyi*. Since such competitors will also compete with pelagic fish, such an approach would require great caution. The Group does not advocate this approach.

(d) Introduction of predators of *Mnemiopsis leidyi*.

The only vertebrate predators that were discussed were fish. For any introductions of fish predators, the following prerequisites were generally agreed on:

(i) the fish must be commercially exploitable, with both domestic and export potential;
(ii) the fish must be disease free and quarantined;
(iii) it must feed heavily on *Mnemiopsis leidyi*;
(iv) existing facilities and skills for its culture must be available in the Black Sea region; and
(v) before any release is undertaken, there must be basic knowledge on its feeding specificity, environmental tolerance, ecological impact and suitability for maintenance, rearing and transport to the Black Sea region.

There are a large number of potential fish candidates for introduction. A discussion of all of them is outside the scope of this report. Over 400 species of fish are known to eat gelatinous zooplankton, and of these, gelatinous zooplankton constitute a major dietary component in more than 100 species (Harbison, in preparation). Three examples of the latter group illustrate the way in which the advantages and disadvantages of specific introductions may be determined. The three fish were *Gadus morhua*, *Oncorhynchus keta*, and *Peprilus triacanthus*. The Group does not regard these as necessarily the best candidates, and they are used only as examples. The advantages and disadvantages of the introduction of each of these three examples are discussed below and listed in Table 8.

The Baltic cod, *Gadus morhua callarias*, is a commercially valuable temperate species that might be a candidate for introduction into the cooler intermediate layer of the Black Sea. The hydrological conditions (temperature, salinity and dissolved oxygen concentration) in this layer are very similar to those in the western Baltic Sea. The potential success of such an introduction has been discussed by Rass and Shiganova (1990). It appears so promising that the USSR Committee on Acclimatization gave approval for the introduction of 500 small cod into the Black Sea in 1988, but this introduction has not yet been carried out. Other advantages are that it is not likely to enter the Mediterranean, and its breeding in captivity is well known. Since it is omnivorous, it will eat non-commercial fish. It is not yet known, however, if it will eat *Mnemiopsis leidyi*, although it eats other ctenophores, particularly *Beroe cucumis* (Kamshilov, 1960; Novikova, 1965). Among the disadvantages are the facts that it will also eat commercially valuable fish, its eggs and larvae might be vulnerable to predation by *Mnemiopsis leidyi*, or the eggs may sink into the anoxic layer. On the other hand, cod are known to live in lakes with anoxic bottom water. Should it be proven that *G. morhua* does not eat *M. leidyi*, this may be an argument for the introduction of the American species of *Beroe*, which is extremely likely to be a food resource for the cod. Since *G. morhua* cannot live in temperatures above 14° C, it will be unable to feed on the bulk of the *M. leidyi* population residing in summer in the warmer surface layer.

Oncorhynchus keta, the Chum salmon, is an anadromous salmonid of high commercial value that appears, in contrast to other members of its genus, to have gelatinous zooplankton as a major component of its diet. Its early developmental stages are in fresh water, and thus are not vulnerable to predation by *Mnemiopsis leidyi*. It is easily cultured, and its populations can be controlled in rivers. However, it is not known if it eats *M. leidyi*. Among potential disadvantages are the facts that it is omnivorous on small pelagic fish, it may not be able to establish itself in the rivers that flow into the Black Sea, because of pollution and dams, and it may compete with native salmonids.

Peprilus triacanthus, the butterfish, is a subtropical-temperate coastal species endemic to North America that might be a candidate for introduction into the upper layer of the Black Sea. It is commercially valuable. It is a highly specific feeder on gelatinous zooplankton, and is known to feed on both *Aurelia aurita* and *Mnemiopsis leidyi*, both of which are most abundant in the upper layer of the Black Sea. It can survive for at least two weeks in the laboratory at a salinity of 4 ppt (De Robertis and Harbison, in preparation), and thus can feed on *M. leidyi* over its entire range in the Black Sea. There is evidence that it controls populations of *M. leidyi* in some regions of North America (Oviatt and Kremer, 1977), and it is easy to maintain in the laboratory. Among the disadvantages of its introduction are the facts that its reproductive biology is poorly known, its eggs and larvae may be vulnerable to predation by *M. leidyi*, and that it may enter the Mediterranean.

Table 8: Three examples of fish that could be considered for introduction into the Black Sea to control *Mnemiopsis leidyi* outbreaks

Habitat:	Coastal	Deep/open water	Anadromous
	e.g. Butterfish (*Peprilus triacanthus*)	e.g. Cod (*Gadus morhua*)	e.g. Chum salmon (*Oncorhynchus keta*)
Advantages	1) Commercially quite valuable. 2) Highly selective feeding on jellies. 3) Evidence for control of *M. leidyi* in areas of North America.	1) High commercial value. 2) Will not enter Mediterranean. 3) Breeding well known (in Norway, sea ranching is being studied). 4) Breeding in Black Sea? 5) May also eat non-commercial fish.	1) High commercial value. 2) Eats a range of gelatinous organisms (But will it eat *Mnemiopsis leidyi*?). 3) Larval stage in fresh water is immune to *M. leidyi*. 4) Easily cultured. 5) Populations can be controlled in rivers.
Disadvantages	1) Reproduction poorly known. 2) Breeds off-shore. 3) Not yet cultured. 4) Eggs and larvae may be eaten by *M. leidyi*. 5) May enter Mediterranean.	1) Omnivorous (also eats fish and benthos). 2) Eggs and larvae may be eaten by *M. leidyi*. 3) Cannot live in all areas where *Mnemiopsis* lives.	1) Omnivorous on small pelagic fish (but more valuable than anchovy). 2) Polluted Black Sea rivers are not necessarily a good natural habitat. 3) May compete with native salmonids.

Many basic aspects of the biology of these species and the more than one hundred other candidates that are presently known must each be summarized with regard to their preference for feeding on *Mnemiopsis leidyi,* their environmental tolerances, ecological impact and their suitability for culture. Such evaluations should be started as soon as possible, focusing in on the optimal candidates.

The only invertebrate predator that was proposed was a species of *Beroe* endemic to the eastern seaboard of the Americas. This species is found in estuaries in both North and South America, and is often closely associated with populations of *Mnemiopsis leidyi*. Although 4 or 5 species of *Beroe* inhabit the Mediterranean, none are the same species as this one (Harbison, pers. observ.), and none of the Mediterranean species have occurred permanently in the Black Sea. This fact underscores the importance of studying the ecology of an exotic species in its home range, where predators have evolved to exploit it.

The species of *Beroe* endemic to the Americas has two outstanding advantages: Firstly, it is highly specific in its feeding, so that even its larval stage feeds on *Mnemiopsis leidyi*. Secondly, its reproductive rate and fecundity are almost as great as that of *M. leidyi*, so that its populations can grow at similar rates to its prey.

Four disadvantages to considering *Beroe* were pointed out. *Beroe* sp. is probably not a potential food resource for Black Sea fish (but see the discussion of *Gadus morhua*, above). *Beroe* has not been found in salinities lower than 10 ppt in Chesapeake Bay (J. Purcell, pers. comm.), and therefore may not be able to penetrate all the areas that *Mnemiopsis leidyi* inhabits. Therefore it could not control *M. leidyi* populations in regions of lowest salinity. It should be noted that the salinity tolerance of this species has not yet been precisely established, and requires further research. The potential impact of the large populations of this species of *Beroe* that would be attained if it successfully controls *M. leidyi* populations on the Black Sea ecosystem is unknown, since, like *M. leidyi* now, it appears that it would have no predators in the Black Sea.

There is obviously a need for great caution in any program that involves the introduction of exotic species into the Black Sea ecosystem. Thus such an introduction should not be advocated unless there is unanimity of opinion by coastal States as to its benign nature (see GFCM, 1993). Proof as to the direction and magnitude of any effect of the introduction can only be obtained from existing information and experiments as necessary. This work should be commenced as soon as possible. Release into the Black Sea should not occur until predicted non-benign effects are rejected. It is expected that such proof will require several years of research and evaluation, at minimum, to achieve for each species investigated.

It is important to keep in mind, at this stage of our knowledge, that research efforts on the biological control of *Mnemiopsis leidyi* should not be restricted to a single species. Many species should be investigated. The most effective approach might be to try several species at once. Investigations of species and strategies should be conducted, not only in the Black Sea region, but also in the home range of *M. leidyi*.

The Group is well aware of the potential problems that may be created by the introduction of exotic predators on *Mnemiopsis leidyi*. However, it points out that biological pollution is fundamentally different from chemical pollution, in that it is self-replicating. One cannot simply remove or neutralize "the pollutant".

Once an invading species is established, as in this case, efforts to keep its numbers in check and thus restore the food chain must be applied continuously. At present, the only feasible control method of continuous application is biological control.

The control of *Mnemiopsis leidyi* populations in the Black Sea through the introduction of species that preferentially feed upon it will not only benefit pelagic fish, but also planktonic and benthic organisms with planktonic larval stages, by reduction of the predatory and competitive pressures of the ctenophore. Because it is so generalized in its feeding, effects of *Mnemiopsis* on the ecosystem are far-reaching and deleterious to the preservation of the already limited biodiversity of the Black Sea. The effect of a highly specific predator on *M. leidyi* will be to decrease the ability of the ctenophore to continue to distort the trophic structure of the Black Sea, and thus will reduce its role as a keystone predator. Therefore, a carefully thought-out and tested biological control programme will be beneficial to the Black Sea ecosystem, and will aid in preserving its marine biodiversity.

7.4 Prevention of the Exportation of *Mnemiopsis* from the Black Sea to Western/Northern Europe and Other Regions of the World

The introduction and establishment of the American comb jelly, *Mnemiopsis leidyi*, in the Black Sea means that the Black Sea region in general, and specifically ports in Russia, Ukraine, Georgia, Bulgaria, Romania, and Turkey, are now exporting sites of *Mnemiopsis* through ocean-going vessels loading ballast water. That is, the Black Sea region has become a new centre of distribution for *Mnemiopsis* as it interfaces with new shipping routes.

There is a potential to transport *Mnemiopsis* from the Black Sea to the Caspian Sea in ballast water. It would be useful, therefore, if vessels passing from the Black Sea to the Caspian Sea were to exchange their ballast water (as discussed below) in the freshwater sections of the river and canal sections between the two seas.

Due to several striking similarities between the Black Sea and the Baltic Sea with regard to their hydrographic and biological features, the Baltic is obviously more open to immigration of exotics from the Black Sea, and *vice versa*, than are the more marine European seas. The Baltic Sea is under natural and man-induced stress and, therefore, receptive to the introduction of opportunistic settlers from other brackish-water seas. From this point of view the Baltic is to be regarded as an area of special concern related to the *Mnemiopsis* outbreak.

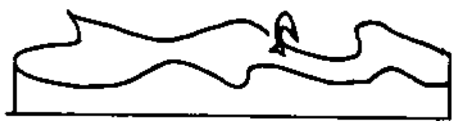
Mnemiopsis is to be regarded as a potential invader. ICES and FAO have expressed fears that it might spread further in European waters. Predicted risks with further introductions of alien species were considered by the HELCOM Environment Committee in 1994.

International mechanisms are in place by which ships visiting Black Sea ports may be advised of the presence of *Mnemiopsis*. For example, in 1988 the International Chamber of Shipping (ICS) in London issued a notice advising ships that there were blooms of the planktonic alga, *Chrysochromulina polyepis* ,on the Norwegian coast, and that ships should use caution as to where they discharge ballast loaded in infested Norwegian waters. In addition, individual nations may issue port advisories in the form of information letters or educational pamphlets (such pamphlets have been issued by Australia, Canada, and the United States). The United States example is shown in Figure 16.

higher diversity and number of species than the open ocean. Most open ocean species are unique to the high seas and generally do not and cannot live in the near shore envioronment.
Exchanging near shore ballast in mid-ocean replaces the diverse, abundant and highly adaptable organisms with fewer and less diverse open ocean organisms intolerant of the fresh water found in the Great Lakes. The risk of discharging this exchanged ballast water into the Great Lakes is considered acceptable.
The ballast exchange concept was chosen by resource managers, regulatory agencies and the shipping industry because it provides an economical and efficient means of reducing the risk of invasion.

Future Action
Biological invasion is recognized as a global problem. The International Maritime Organization (IMO) has developed International Guidelines for Preventing the Introduction of Unwanted Aquatic Organisms and Pathogens via Ships' Ballast Water and Sediment Discharges. These guidelines have been offered to IMO Member States for adoption.
The U.S. will issue regulations to reduce the risk of introducing exotic species into the Great Lakes through ballast water by December 1, 1992.
Alternative ballast water control and treatment methods for minimizing the risk of exotic species invasion are being investigated.

For Further Information
U.S. Coast Guard Marine Safety Detachment, Massena, New York provides information and educational assistance on the Great Lakes ballast exchange program.
For information call: (315) 764-3284.



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U.S. Department
of Transportation
United States
Coast Guard

Ballast Water

- a source of invasion -

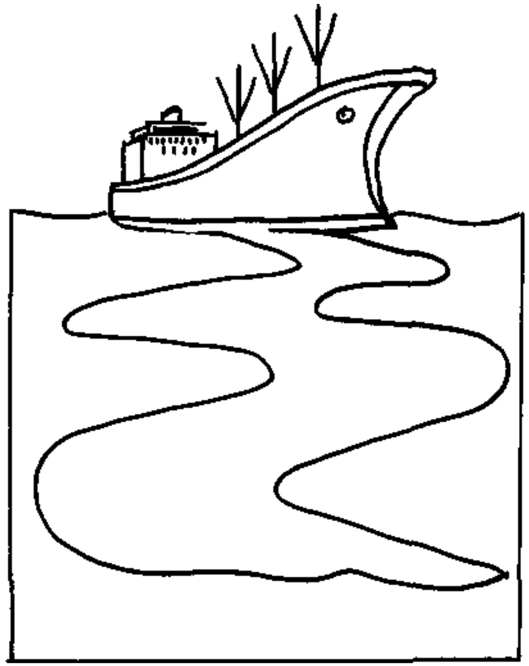


Figure 16: Ballast Water - a source of invasion
(U.S. Department of Transportation, United States Coast Guard)
(continued overleaf)

Figure 16 *(continued)*

The Exotic Species Problem

The Great Lakes and other water bodies of the world are being invaded by non-native aquatic species, also known as exotic species. The biological invaders are arriving in ships ballast water and sediment and are being discharged by unsuspecting mariners to siege native aquatic environments.

The problem is that successful invaders usually have detrimental effects on native species, their habitats and human activities dependent on the water's resources. Once exotic species establish themselves, eradication becomes impossible without further damaging the environment and native species. Successful invaders become permanent additions to the environment.

Ballast Water–A Source of Invasion

Biological invasion can occur when ships discharge ballast water taken in foreign ports or near shore waters into the Great Lakes. If the aquatic plants and animals species introduced by ballast water and sediment are compatible with the physical and ecological conditions of the lakes, they survive, reproduce and disperse throughout the environment. The large amounts of ballast water carried by ships, their increasing speeds of transit between ports and the improving water quality worldwide all contribute to the success of the invasion process.

Characteristics of Successful invaders

Not all aquatic species transported by ballast water and introduced to new environments will be successful invaders-in fact, most fail. The ones that succeed display common characteristics that make them successful. They are hardy, capable of surviving the voyage in ballast water. They are aggressive, capable of displacing native species. They are prolific breeders, capable of expanding their population rapidly. And they disperse rapidly, capable of affecting new environments.

The Effects of Invasion

Successful exotics have the infamous ability to spoil native habitat, threaten native plant and animal species diversity and abundance, and disrupt human social and economic activities dependent on the aquatic resources. These impacts are more likely to be felt in areas where the exotic species has no natural predators or competition; or in areas where there are few native species to compete with or resist its invasion. These two indicators apply to the great Lakes problem. Exotics transported by ballast water are freed from the pressures of their native environment and the Great Lakes have relatively few species to compete with invaders. Consequently, the Great Lakes are vulnerable to invasion.

The Great Lakes Situation

Three recent invaders introduced to the Great Lakes by ballast water have achieved success in their new environment at the expensse of other native species. These include the zebra mussel, the European ruffe and the spiny water flea.

The zebra mussel, introduced to the Great Lakes in 1986, is an excellent example of an exotic species' harmful potential. Spreading throughout the Great Lakes, the zebra mussel threatens the entire food web by removing vast amounts of basic food material from the ecosystem. This means less food energy is available to sustain native species dependent on this food source. Some natives species may vanish from the lakes as a result. Ecological damages are still being assessed.

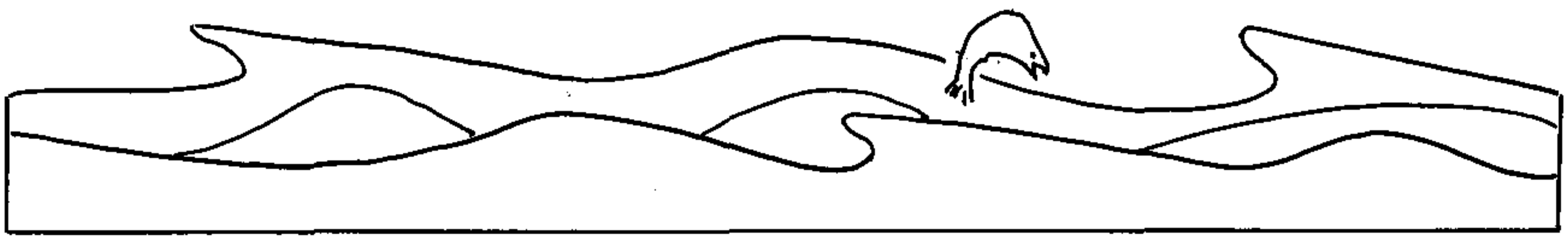
People also suffer the economic and social consequences of invasion. Raw water intakes for industries, power plants, crop irrigation and public drinking water are being fouled, upsetting industrial and food production, and basic public sservices. Jobs dependent on stable commercial and sport fisheries may be lost due to the disruption of native fish species. Public agencies faced with managing these serious resource problems expend limited public funds and personnel resources that could otherwise be directed to other critical projects.

Ballast Water Management

Voluntary Guidelines for Control of Ballast Water in the Great Lakes were established by the U.S. and Canadian Coast Guards to reduce the probability of introducing new exotic species into the Great Lakes. If you have been to the lakes since May 1989, you may have participated in the ballast exchange program. Compliance has been high, 83% in 1989 and 96% in 1990. You can help continue this upward trend by your strict adherence to the guidelines. Guidelines are available through the U.S. Coast Guard detachment listed on the following page.

The following facts may help you better understand the ballast exchange concept.

The concept. Near shore and port environments where ships usually take on ballast water support a



The International Maritime Organization (IMO) has issued, through its Marine Environment Protection Committee (MEPC), globally applicable guidelines concerning the uptake, exchange, and discharge of ballast water, which in 1993 were adopted as resolution A.774(18) by IMO' Assembly. IMO advises that ships carrying ballast water attempt to exchange their water on the high seas (open sea) in order to prevent the transport and introduction of organisms from one coast to another coast. Thus, for example, a vessel departing the Black Sea for a Pacific Ocean port would be advised to attempt to release its ballast water in the mid-Atlantic Ocean or mid-Pacific Ocean and reballast with oceanic water (and thus with oceanic planktonic organisms). As it is widely recognized that ships may not be able to exchange their water under certain sea conditions and that ships may be able only to undertake partial exchange, various countries (including the USA, Canada, and Australia) are studying alternative ballast management options. In addition, IMO is currently considering the development of legally binding provisions together with guidelines for their implementation. In the meantime, however, the prevention of the uptake of organisms from known infested waters, combined with attempts at open sea ballast exchange, are considered two of the best immediate, short-term strategies for the reduction of the risk of invasions by exotic species.

7.5 Prevention of Future Accidental Invasions into the Black and Azov Seas and the Sea of Marmara Through the Release of Ballast Water

A stream of invasions usually continues to occur wherever ballast water is released. Ballast water from around the world continues to be released in the Black Sea. It is predicted that this region will sustain one or more serious invasions by new exotic species before the close of the 20th century.

There is a mechanism in place to greatly reduce the risk of, but not absolutely prevent, future invasions. As noted above, the International Maritime Organization (IMO) has issued voluntary guidelines advising ocean-going vessels to attempt to exchange their ballast water on the high seas (open sea). The nations of the Black Sea region could alert inbound (incoming) ships to the existence of these guidelines. Thus, a vessel coming from the Chesapeake Bay in the United States (where blooms of the omnivorous, stinging jellyfish *Chrysaora* have been occurring), would attempt to exchange their Chesapeake Bay water in the mid-Atlantic Ocean. Problems with undertaking exchange or accomplishing full exchange (as discussed above) have led some IMO member countries to begin to study other ballast management options, but high seas exchange is now considered a useful first step to reduce the risk of accidental transportation.

Ships both with and without cargo carry ballast water. The amounts of water carried in ships with cargo are typically small and may consist, for example, of a 1000 metric tons of water in forepeak ballast tanks to lower the vessel's bow. Nonetheless, even small amounts of water (from the mariner's point of view) may be of considerable importance in terms of the living organisms it carries (from the biologist's points of view).

8 Summary - Conclusions, Recommendations, Research

During its two meetings in 1994 and 1995, the GESAMP Working Group identified areas of controversy, conclusions and recommendations, and research directions and needs. This discussion within GESAMP formed the basis of the sections below.

8.1 Areas of Controversy

Two topics did not receive consensus:

(1) the design of an additional relevant monitoring program - the priority for conducting additional monitoring of the pelagic fish versus higher trophic level zooplankton, and the use of major vessels infrequently compared with smaller boats in-shore very frequently; and

(2) potential of the American species of *Beroe* to enter, if introduced, into all habitats of the *Mnemiopsis* presently occupied in the Black Sea Region.

8.2 Conclusions and Recommendations

The Group reached the following set of general conclusions and recommendations:

(1) The state of the Black Sea ecosystem cannot be restored to its condition before the 1940s for the following reasons:

(a) human activities have increased both within and around the Black Sea;
(b) agricultural and industrial activities have increased;
(c) the flow of rivers has been altered in volume and quality; and
(d) six exotic species have had a significant impact on the Black Sea (crab *Rhithropanopeus harrisi*, snail *Rapana thomasiana*, clam *Mya arenaria*, fish *Mugil soiuy*, comb jelly *Mnemiopsis leidyi*, clam *Cunearca cornea*);

(2) the goals of any project for the rehabilitation of the Black Sea must be directed at both the environmental and economic improvement of the region. It is recognized that these objectives may be in conflict in some cases. However, given the irreversibly altered ecosystem with which the Black Sea States are now confronted, this documented strategy for the reduction of *Mnemiopsis leidyi* populations will contribute to progress towards both goals;

(3) rehabilitation of pelagic fish stocks along with the reduction of *Mnemiopsis leidyi* populations will require both their sustainable exploitation and improvement of the Black and Azov Seas environments;

(4) biological control is the most practical method for controlling *Mnemiopsis* populations in the Black Sea region. The preferred strategies of biological control are:

(a) the management of fisheries so as to enhance populations of indigenous fish competing with or grazing on *Mnemiopsis*;

(b) the introduction of economically valuable, specific predators of *Mnemiopsis*, such as the fish *Gadus*, *Peprilus* or *Oncorhynchus*; and

(c) the introduction of a comb jelly-specific predator i.e. *Beroe* sp.

It is recommended that the three strategies be evaluated further and pursued simultaneously in each part of the Black Sea region experiencing *Mnemiopsis* outbreaks;

(5) improvements of coordination among institutions, national and international programmes in the areas of scientific research, monitoring activity and control measures are essential for optimizing the success of the recommended strategies;

(6) finding an approach to control populations of *Mnemiopsis leidyi* is very important for the natural restoration of the Black Sea Region and the re-establishment of economic productivity. It is also an important example for other regions of the world (e.g., Caspian Sea, Gulf of Venice, Adriatic Sea, Baltic Sea);

(7) international attempts should be made to reduce the risk of exportation of *Mnemiopsis* from the Black Sea Region and the importation of further accidental introductions;

(8) international co-operation is essential for solving this problem, and should remain a high priority of the appropriate United Nations agencies, the riparian states of the Black Sea Region, and the international community. Improved coordination between research, monitoring, and control activities in the Black Sea region is essential;

(9) it is recommended that a permanent Working Group on The Control of Marine Pest Invasions be established through a global mechanism such as GESAMP. Such a group would advise and recommend strategies on the prevention and post-introduction research and control of introduced species, and would communicate with other international agencies;

(10) studies on *Mnemiopsis* must continue on its seasonal dynamics, regions of distribution, conditions of reproduction and feeding, and its impact on ecosystems and fisheries (finfish and shellfish) in the Black Sea Region; and

(11) studies on mechanisms and possibilities of control must be undertaken immediately in order to find and confirm potential controlling species and/or develop other options.

8.3 Research Directions and Needs for Monitoring and Control

The Group recognized that funding requirements for a thorough investigation of all aspects of the problem raised above will greatly exceed available sources. However, a limited list of useful projects was thought to be useful, especially those that could be done with limited funding, and those amenable to co-operative work between institutes in the Black Sea Region and in the North American home range for the species. These are presented below, in priority:

8.3.1 Research Related to Monitoring of the Ctenophore Outbreak

The following research related to continued monitoring of the ctenophore and its effects is suggested, grouped as high and low priority items:

High Priority (not in order) - Immediate

(1) elucidate population dynamics and interactions between *Mnemiopsis leidyi* and other planktonic organisms in Black and Azov Seas;

(2) carry out modelling of ecosystem components, at various levels of space, season and time, up to the main exploitable pelagic fish stocks and *Mnemiopsis;*

(3) determine risk of transport and dispersion rates of *Mnemiopsis* from the Black and Azov Seas by ships to other parts of the world;

(4) clarify impacts of decaying *Mnemiopsis* biomass and mucus on pelagic and benthic ecosystems;

(5) elucidate interaction of *Mnemiopsis* with small pelagic fish in selected areas of the Black Sea region, and with emphasis on upper trophic level components of the ecosystem (i.e. the predatory fish);

(6) identify distribution and occurrence of *Mnemiopsis* and *Beroe sp.* in the Marmara Sea, and related seas, with the assistance of local fishermen and their communities;

Low Priority

(7) determine genetic typing (i.e. fingerprinting) of *Mnemiopsis* populations globally, to understand origins of the species and its population ecology in different water bodies.

8.3.2 Research for Control of the Ctenophore Outbreak

The following research essential for control of the ctenophore outbreak was suggested, organized in high and low priority:

High Priority (not in order) - Immediate

(1) study the feeding and food preference of indigenous and Western Hemisphere fish and *Mnemiopsis*, using copepods, *Pleurobrachia, Aurelia* and *Noctiluca*, and fish larvae;

(2) identify additional predators of *Mnemiopsis* from the Americas and other regions;

(3) identify salinity and temperature tolerance of *Mnemiopsis* spp. and *Beroe* spp., including the species of *Beroe* indigenous to the Americas. Broader studies of their biology and physiology;

(4) carry out experimental and field studies of *Mnemiopsis* - morphology, growth rates, fecundity, generation times, and feeding rates in different water masses of the Black Sea. Optimum conditions for its survival, growth and reproduction;

(5) study the electivity and environmental tolerance of prospective predator fish species, so as to identify suitable species for application to *Mnemiopsis* outbreaks in the Black and Azov Seas;

(6) confirm predation and predation rates of *Beroe* on both *Mnemiopsis* and *Pleurobrachia* through experimental and field studies;

(7) find and verify predators by determining the significance of *Mnemiopsis* diet of indigenous species;

(8) determine the taxonomy of *Beroe spp.* in the Atlantic and Mediterranean Seas;

(9) encourage the donor agencies to provide support for relevant aquaculture and sea farming efforts for known predators of *Mnemiopsis*;

(10) introduce controls on the fishing effort for small pelagic fish;

(11) enhance clearing efforts of coastal and riverine environments that are needed for coastal fish species to replace depleted demersal stocks;

(12) focus and adapt monitoring and research on control measures to the available skilled manpower and facilities in the Black Sea Region;

Low Priority (not in order)

(13) study the diseases and parasites of *Mnemiopsis*;

(14) confirm predation and predation rates of *Beroe* on both *Mnemiopsis* and *Pleurobrachia* through experimental and field studies;

(15) develop a methodology for identifying ctenophores in fish stomachs (possibly using biochemical or genetic tools).

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ANNEX 1

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ANNEX 2

EXTRACTS FROM GENERAL FISHERIES COUNCIL FOR THE MEDITERRANEAN (GFCM) REPORT

Mnemiopsis control measures:

Experts expressed the opinion that immediate attention should be paid to the population explosion of a predatory Ctenophora, "*Mnemiopsis leidyi*", which competes with fish species for food, and over the last two years has led to collapse of pelagic fish stocks. Speedy action to control the devastating effect of this Ctenophora is essential in the international effort to rehabilitate the Black and Azov Seas. Ideally, studies on the total ecosystem should be conducted, encompassing the dynamics of the foodweb, recruitment and fish populations. Pending the design of a co-operative comprehensive research programme on the subject, the Consultation recommended that a Task Force be established to identify the ways and means of biological control of the *Mnemiopsis* populations. To this end, a 3 stage action program is proposed:

Stage 1. Statement of the problem, identification of potential solutions.

Stage 2. Selection of species which could be used for the biological control. Development of intervention plans; development of methodologies to rear, transport and maintain the species of predators that may be introduced. Monitoring of the *Mnemiopsis* will be carried out on a regular basis. Preference will be given to indigenous species if it proves that the required level of control can be achieved. Experiments in control of *Mnemiopsis* will be carried out in closed quarantined systems.

Stage 3. The consensus of the Black Sea riparian countries will be obtained before release of biological control agents into the Black Sea, and their progress monitored with regular surveys.

The Action Plan should include an intensified sampling and modelling effort to clarify the trophic chains involving *Mnemiopsis* and commercial fish species.

The Task Force will supplement the work already conducted by Harbison and Volovik by synthesizing the additional information that may be available on the subject; will identify potential predators, study the feeding preferences of those predatory species indigenous to the Black Sea, while monitoring the state of the *Mnemiopsis* populations. They will also develop a strategy and Action Plan for *Mnemiopsis* control, and convene a scientific meeting attended by the experts from the riparian countries of the region, supplemented, as required, by experts from other areas,to secure consensus on the implementation of the Action Plan.

Mnemiopsis Control:

Taking note of the urgency in controlling the population explosion of *Mnemiopsis*, the Technical consultations requested the establishment of a task force to develop a strategy and an action plan,

Considering that the control of the biological pollution (in this case this refers mainly to *Mnemiopsis*) is an integral part of the efforts in the rehabilitation of the Black Sea ecosystem,

Urges the GEF to include this Action Plan, to be developed by a task force of scientists from coastal States, in its Program of Environmental Management and Protection of the Black Sea, and finance the program activities as a matter of urgency.

ANNEX 3

PRESENT STATE OF ZOOPLANKTON IN THE ROMANIA BLACK SEA WATERS[4]

Dr. Adriana Petranu

The consequences of the environmental changes in the Black Sea following the increase of human influences, first of all the increase of eutrophication, of primary production and of organic matter content in the water, have been reflected by the zooplanktonic biocenosis as well.

The global space-time evolution of zooplanktonic communities from Romania Black Sea waters has evinced in the last two decades the tendency of some changes in the species composition and in the quantitative ratios among component species.

In the new circumstances are noted:

- the disappearance of some sensitive species (such as hyponeustonic species of copepods in the Pontellidae family);
- the reduction in the populations of some holoplanktonic species (for copepod *Centropages Ponticus*, the cladocerans (*Penilia avirostris*, *Evadne tergestina*), or in the populations of meroplanktonic forms, especially larval stages of molluscs, as a consequence of the mortalities noted in the benthic fauna;
- an exuberant development of a small number of opportunistic species, which have induced high values of densities and biomasses, and have compensated in a way the reduction of the zooplanktonic population rather sensitive. These were herbivorous and detritivorous opportunistic species with sudden development in the conditions of the quantitative increase of the phytoplankton and dissolved organic matter.

The main component group and numerically the largest components of the zooplankton were copepods, with a higher percentage in the formation of the zooplankton annual mean density and biomass.

Their biological productivity growth within the 1980-1986 period; the general tendency of the biomass index time evolution present a five times increase of its mean annual value for the 9th decade, as compared with the previous decade.

In conditions of intensification of the eutrophication process, a few species of copepods received a significant importance in zooplanktonic communities.

In the first place was *Acartia clausi*, whose development has had an explosive character in the 9th decade, evidenced by its biomass growth, eight times higher than in the previous decade.

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[4] Original unedited copy 1994.

The importance of *Acartia clausi* in the formation of Copepoda populations increased to 68% in 1980-1987.

Next in order of importance in biomass were *Oithona nana* representing 10% in total group biomass and *Pseudocalanus elongatus* with 8% of copepods biomass.

Besides the above-mentioned species of copepods, one species of cladocerans - *Pleopis polyphemoides* - has had big densities and biomasses in this period. Especially during the summer, *Pleopis* together with *Acartia clausi* dominated in the quantitative structure of the zooplankton in the 30-40 miles offshore zone and have produced an increase of the quantitative indicators (density and biomass) of the trophic zooplankton.

In 1980-1987 the mean values at the Romania littoral were in continuous increase (six times higher than the means in the decade 1960-1970).

That was an important trophic potential for the fish feeding on plankton, especially for *Sprattus sprattus* whose protection was increasing for the mentioned period.

Until 1988, the maximum abundance moments with highest values of biomass of those species occurred in warm seasons on the surface waters and were produced usually by the phytoplanktonic blooms.

Besides the mentioned zooplanktonic organisms having a trophic part in the ecosystem (highly caloric zooplankton), some species with low caloric value developed exuberantly. The first of them is the cystoflagelate *Noctiluca scintillans* which has had the most spectacular quantitative development during the last decade. The densities and biomasses of this species in the 9th decade were about ten times higher than in the previous period (1970-1980). Between 1980 and 1986, the mean annual density was never less than 100,000 ind. m^3 (in August 1987 in the waters near to Constantza were 2,048,000 ind. m^3 and 164 $g.m^3$).

At the Romania littoral of the Black Sea, *Noctiluca scintillans* have represented 91-99,9% of the general biomass during the summers of 1986-1991.

The excessive development of *Noctiluca* in these years in the Romania marine waters and generally in the Black Sea could be considered in connection with a synergic action of some environmental factors. Among them, phytoplankton abundance plays a first role in the form of repeated and intense water "bloom".

The massive development of *Noctiluca* is preceded usually by the occurrence of a push of one or another species of diatoms and peridiniens, who represent now an abundant food resource, even excedentary.

In these years, medusa Aurelia aurita played an important role in the Black Sea plankton. Its population grew explosively too. The quantitative increase of this jellyfish has resulted in a decrease of the number of fish feeding on plankton, competing for food.

The evolution of zooplankton quantities for the last seven years (1986-1992) in Romania marine waters makes it clear a different dynamic for the total zooplankton (including Noctiluca), and so-called trophic zooplankton (highly caloric zooplankton) including only organisms representing trophic resources, ensuring the transfer level of the energetic flux in the ecosystem (copepods, cladocerans, meroplankton, rotifira, ciliates).

Thus, while the total biomasses were increasing from 1986 until 1990, owing to the blooms of *noctiluca*, the trophic zooplankton biomasses decreased, so that in 1988 lower quantitative indicators of density and biomass were recorded.

So, during the last 5-6 years (beginning in 1988), a degradation of the zooplanktonic communities has been noted; their situation became very precarious, especially during the summer, a severe reduction of populations being registered for most of the groups of organisms with trophic value. In 1990 and 1991, the mean values of the trophic zooplankton densities were six to seven times smaller than in 1989 due to the fact that even the species with intensive growth during the previous years (1980-1987), such as *Acartia clausi*, *Pleopis polyphemoides*, have had a very low quantitative level. In 1992 the mean values of densities and biomasses were a little higher than the previous two years due to the copepod *Calanus ponticus*.

This decrease of zooplankton has been correlated with a spectacular reduction of the catches of fish feeding on plankton. In the Romania fishery, the anchovy production decreased from 6,354 tons in 1984 to 1,946 t. in 1988, 66 t. in 1989 and only 5 t. in 1990; the production of sprat was 8,912 t. in 1989, 3,198 t. in 1990 and 720 t. in 1991; the production of horse mackerel was reduced from 1,459 t. in 1988 to 165 t. in 1990.

The decrease for all zooplanktonic species with a trophic part in the coastal ecosystem during the last 5-6 years must be attributed to a great extent to a new migrator in the pelagic zone of the Black Sea - the opportunistic carnivorous, the predatory ctenophore - *Mnemiopsis leidyi*.

Seasonal observations showed that beginning with 1989 the saplings of *Mnemiopsis leidyi* were founded in the Romania waters, its minimum quantity was observed in spring and the pronounced peak corresponds to summer in June-August. In November 1993, in the shallow waters in front of Constantza a great number of saplings of *Mnemiopsis* with a size of 1-3 cm were observed.

The decrease of the quantitative level of zooplankton, including mostly filtrating herbivorous species, has caused the reduction of the number of consumers of phytoplankton which was excessive anyway, contributing to the creation of an important surplus of primary production. Without control of herbivore standing stock of phytoplankton increase rapidly and lead to blooms.

Aurelia aurita and later *Mnemiopsis* not being predated, also have contributed to the organic material precipitated on the shelf, at the end of their short life histories.

Owing to its highly significant effect on the production of trophic zooplankton, *Mnemiopsis* acts as a serious trophic rival of food for plankton - eating fish, causing the reduction of their stock.

The impact of *Mnemiopsis* on the pelagic communities of the Black Sea has produced during recent years a more disastrous effect than any other anthropogenic influences.

ANNEX 4

MONITORING GUIDELINES FOR *MNEMIOPSIS*

Due to the critical importance of the problem, the following advice is offered as early guidance:

1. Areas: For observations the most characteristic standard stations should be established (some 5-6) covering both gyres, the convergence in the central region, the NE, NW and southern and eastern shelfs.

2. Timetable: Each year, at least two expedition cruises should be recommended. Timing of cruises should be consistent with the regional biological development of *Mnemiopsis*.

Some experts felt that more frequent sampling of the more shallow coastal waters using small vessels or boats would enhance the probability of finding *Mnemiopsis* during the year.

3. Monitoring scope: The following parameters are recommended to be estimated during the monitoring missions:

   - Environmental parameters: STD profiles, oxygen, nutrients.

   - General microplankton and productivity parameters: composition and biomass of phytoplankton, bacterioplankton, planktonic protozoa, primary production.

   - Zooplankton parameters: composition and abundance of small copepods and other small-size zooplankters dwelling in the upper mixed layer e.g. *Calanus euxinus*, *Sagitta setosa*, *Aurelia aurita*.

   - *Mnemiopsis* parameters: numerical abundance, vertical distribution, size composition of populations, biomass.

   - Ichthyoplankton parameters: trawler sampling of spawning anchovies stocks; sampling of ichthyoplankton for estimation of the spring-spawning fish; sampling of fry.

   - Standardization: All observations listed above should be made using standard methods, agreed to and intercalibrated by participants of the monitoring programme.

   - The collection and storage of data received: a kind of data bank should be organized and the data should be presented in a form suitable for use in models.

   - Use of other vessels: Scientists from all riparian countries are encouraged to go on fishing vessels or other vessels of opportunity to obtain a seasonal and synoptic picture of the *Mnemiopsis* distribution.

GESAMP Reports and Studies Publications

The following reports and studies are available from any of the Sponsoring Agencies of GESAMP.

Rep. & Stud. No.	Title	Date
1	Report of the Seventh Session	1975
2	Review of Harmful Substances	1976
3	Scientific Criteria for the Selection of Sites for Dumping of Wastes into the Sea	1975
4	Report of the Eighth Session	1976
5	Principles for Developing Coastal Water Quality Criteria	1976
6	Impact of Oil on the Marine Environment	1977
7	Scientific Aspects of Pollution Arising from the Exploration and Exploitation of the Sea-bed	1977
8	Report of the Ninth Session	1977
9	Report of the Tenth Session	1978
10	Report of the Eleventh Session	1980
11	Marine Pollution Implications of Coastal Area Development	1980
12	Monitoring Biological Variables Related to Marine Pollution	1980
13	Interchange of Pollutants between the Atmosphere and the Oceans	1980
14	Report of the Twelfth Session	1981
15	The Review of the Health of the Oceans	1982
16	Scientific Criteria for the Selection of Waste Disposal Sites at Sea	1982
17	The Evaluation of the Hazards of Harmful Substances Carried by Ships	1982
18	Report of the Thirteenth Session	1983
19	An Oceanographic Model for the Dispersion of Wastes Disposed of in the Deep Sea	1983
20	Marine Pollution Implications of Ocean Energy Development	1984
21	Report of the Fourteenth Session	1984
22	Review of Potentially Harmful Substances Cadmium, Lead and Tin	1985
23	Interchange of Pollutants between the Atmosphere and the Oceans (second report)	1985
24	Thermal Discharges in the Marine Environment	1984
25	Report of the Fifteenth Session	1985
26	Atmospheric Transport of Contaminants into the Mediterranean Region	1985
27	Report of the Sixteenth Session	1986
28	Review of Potentially Harmful Substances. Arsenic, Mercury and Selenium	1986
29	Review of Potentially Harmful Substances. Organosilicon Compounds (Silanes and Siloxanes)	1986
30	Environmental Capacity: An Approach to Marine Pollution Prevention	1986
31	Report of the Seventeenth Session	1987
32	Land-Sea Boundary Flux of Contaminants: Contributions from Rivers	1987

Rep. & Stud. No.	Title	Date
33	Report of the Eighteenth Session	1988
34	Review of Potentially Harmful Substances. Nutrients	1990
35	The Evaluation of the Hazards of Harmful Substances Carried by Ships: Revision of GESAMP Reports and Studies No. 17	1990
36	Pollutant Modification of Atmospheric and Oceanic Processes and Climate: Some Aspects of the Problem	1989
37	Report of the Nineteenth Session	1989
38	Atmospheric Input of Trace Species to the World Ocean	1989
39	The State of the Marine Environment	1990
40	Long-Term Ecological Consequences of Low-Level Contamination of the Marine Environment	1989
41	Report of the Twentieth Session	1990
42	Review of Potentially Harmful Substances. Choosing Priority Organochlorines for Marine Hazard Assessment	1990
43	Coastal Modelling	1990
44	Report of the Twenty-first Session	1991
45	Global Strategies for Marine Environmental Protection	1991
	Addendum 1: Can there be a common framework for managing radioactive and non-radioactive substances to protect the marine environment?	1992
46	Carcinogens: Their Significance as Marine Pollutants	1991
47	Reducing Environmental Impacts of Coastal Aquaculture	1991
48	Global Change and the Air/Sea Exchange of Chemicals	1991
49	Report of the Twenty-second Session	1992
50	Impact of Oil and Related Chemicals and Wastes on the Marine Environment	1993
51	Report of the Twenty-third Session	1993
52	Anthropogenic Influences on Sediment Discharge to the Coastal Zone and Environmental Consequences	1993
53	Report of the Twenty-fourth Session	1994
54	Guidelines for Marine Environmental Assessments	1994
55	Biological indicators and their use in the measurement of the condition of the marine environment	1995
56	Report of the Twenty-fifth Session	1995
57	Monitoring of ecological effects of coastal aquaculture wastes	1996
58	Opportunistic settlers and the problem of the ctenophore *Mnemiopsis leidyi* invasion in the Black Sea	1997
59	The sea-surface microlayer and its role in global change	1995
60	Report of the Twenty-sixth Session	1996
61	The contributions of science to integrated coastal management	1996