Israel Oceanographic and
Limnological Research (IOLR)

The Interuniversity Institute for
Marine Sciences in Eilat (IUI)

Gulf of Eilat Monitoring and Research Program – IET Recommendations

Final Report

Submitted by

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To the Chief Scientists

Ministry of Agriculture
Ministry of the Environment
Ministry of National Infrastructures

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I. Introduction

This is the final report of a comprehensive program of research and monitoring activities (IET Program) commissioned by the Government of Israel to implement the recommendations of the report of the International Expert team (IET) on Evaluation of Pollution in the Gulf of Aqaba / Eilat (GOA) (December 2001). The program lasted from July 2002 to June 2004 and consisted of 14 projects carried out by teams of scientists from the Hebrew University of Jerusalem and Tel-Aviv and Bar-Ilan Universities, all affiliated with the Interuniversity Institute for Marine sciences in Eilat (IUI); from the three research centers of Israel Oceanographic and Limnological Research (IOLR); and from the Geological Survey of Israel.

Most of the projects of the IET Program were specifically recommended by the IET (Projects 6, 7, 8, 9, 11, 12, 18, 22). A few additional projects were designed to provide complementary information related to the issues discussed in the IET report and to other aspects of environmental management of the northern GOA (Projects 16a, 16b, 16c, A, B1, B2, C).

The recommendations of the IET related to research and monitoring activities focused on the need to determine the 'carrying capacity' of the northern GOA for anthropogenic inputs of nutrients, especially from the offshore fish farms in Eilat.
Seven projects of the IET Program addressed different aspects of this issue[1]:
6 – Simulations of the circulation in the GOA with a numerical model;
7 – Analysis of the available chemical data for the GOA;
8 – Fluxes of nutrients from the sediments in the northern GOA;
9 – Continued nutrient measurements in the northern GOA;
11 – Phosphorus in the sediments of the northern GOA;
A – Groundwater input of nutrients in the northern GOA;
C – Nitrogen fixation in the northern GOA.
Because of differences of opinions among the investigators of project # 7 regarding the working methodology, two separate reports were prepared for this project -7a and 7b.

Three projects addressed other environmental issues in the northern GOA:
22 – Mortality and disease in wild fish populations;
B1 – Detergents in coastal waters;
B2 – Organic and metal pollutants in sediments.

Three projects dealt with biological/ecosystem studies[2]:
16a –Metabolic studies in the coral reef at the community level;
16c –Cellular-level biomarkers for stress in corals;
18 – Coral recruitment in the northern GOA; part of
Project # 12 – Analysis of available temperature data for the northern GOA - was designed to provide information relevant to some biological processes.

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[1] An additional project (# 10) on the composition of suspended particulate matter was not completed due to breakdown of the analytical instrumentation required.
[2] An additional project (# 16b) on metabolic studies in the coral reef at the colony level was not completed because the experimental system was destroyed by storms.

All the individual projects reports are presented in Chapter II as submitted by the reporting scientists by the set deadlines. All scientists were informed well in advance that the deadline for submission of final reports was 27 June 2004 except for a deadline of 1 July for projects # 8 and 12. The project reports are grouped under four general headings: Hydrodynamics and physical parameters; Nutrient dynamics and sources; Fish pathogens and organic and metal pollutants; Biomonitoring and biological/ecosystem investigations.

Chapter III of the report presents a brief summary of the conclusions of all Projects along with our comments and overall, integrated conclusions derived from the outcome of the Program. These conclusions reflect our personal scientific judgment and do imply the expression of any opinion whatsoever on the part of our institutions concerning the issues addressed.

We thank all the investigators involved in the IET program for their contribution to the understanding of the environmental problems in the northern GOA and for their efforts to execute the program activities according to the original planning. We thank the ministries of Agriculture, Environment and National Infrastructures for the funding of this program. We are grateful to the Chief Scientists of the three ministries, Prof. Dan Levanon, Dr. Eli Stern and Dr. Michael Beyth, for the overall supervision of the conduct of the program. We thank the following scientists who participated in various discussions of the program activities and results that helped us to lead the program and crystallize our final conclusions (in alphabetical order): Prof. L. Fishelson, Tel-Aviv University; Prof. A. Genin, IUI; Profs. B. Luz and N. Paldor, Hebrew University; Dr. B. Rinkevich, IOLR; Prof. A. Shemesh, Weizman Institute of Science; Prof. G. Winston, Ministry of Health. Finally, we thank the members of the IET, Profs. M.J. Atkinson, H. Rosenthal and Y. Birk for instigating this multifaceted program.

II. Project reports

This chapter is the collection of all project reports of the IET program. Because of its volume it is included separately.

III. An integrated summary and comments of the program results

III.1. Nutrient dynamics in the northern GOA and the possible impact of anthropogenic activities

Anthropogenic nutrient inputs into the northern GOA.

Nutrient dynamics in the GOA are controlled by the variability of biological activity and the hydrodynamic regime. The Gulf is stratified from spring to early winter. During the stratified period, the nutrients in the photic layer (upper water column) are taken up effectively by the primary producers and are subsequently incorporated into the food web to become part of the living particulate organic pool. Part of the particulate organic matter (organisms and organic detritus) is recycled above the thermocline while the rest sinks and decomposes within the lower water column or in the underlying sediments. These remineralization processes lead to a gradual build-up of a deep water nutrient reservoir. Winter mixing transports nutrients from this deep water reservoir back to the photic layer, where they are again incorporated by the primary producers into the particulate pool. During "normal" years, vertical mixing reaches a depth of less than 400m. In winters colder than normal, the vertical mixing may extend all the way to the sea bottom and "reset" the system, depleting the deep water nutrient reservoir and reducing nutrient concentrations to very low levels. Such deep mixing events were recorded in the years 1976, 1989, 1992, 1993 and 2000.

As mentioned in the Introduction, the focus of the IET recommendations and hence of the IET program, was the 'carrying capacity' of the northern GOA to anthropogenic inputs of nutrients or, in other words, to what extent are such inputs likely to affect the nutrient cycle described above. Concern had been expressed that the excessive accumulation of nutrients in deep water due to anthropogenic inputs could subsequently lead to increased nutrient levels in the photic layer following deep mixing events. In turn, this could result in massive algal blooms with adverse ecological impact especially on the coral reefs.

Routine marine discharge of sewage by the cities of Eilat and Aqaba was discontinued in the mid 1990's. Since then, the largest known anthropogenic input of both nitrogen (N) and phosphorus (P) into the northern GOA has been from the offshore fish farms in Eilat (~ 200 – 300 ton N and 20 – 25 ton bioavailable P annually since 1997). Submarine groundwater discharge is another potential source of nutrients that was assessed in Project A. The conclusion was that the present annual flux of N into the northern GOA through the groundwater system is ~ 30 ton (the error margin of this figure may be large, but is probably less than an order of magnitude). This figure, of about one order of magnitude below the fish farms output, is in keeping with that of a recent radium isotopes study by a group from Stanford University (G. Shellenbarger and A. Paytan – pers. comm., report available on request).

Another source of P is phosphate ore dust from loading operations in the ports of Eilat and Aqaba. As noted by the IET, excess of dust-born P in the surface waters may stimulate nitrogen fixation and hence introduction of new N into the food chain. Several studies documented blooms of nitrogen- fixing *Tricodesmium* spp. colonies in the northern GOA during the stratified period in the 1990's, but the amount of nitrogen fixation was not quantified. The possibility of nitrogen fixation was examined in Project C. On the four occasions that GOA water were sampled (early summer 2002, winter 2002 and fall 2003), nitrogen fixation was not recorded and *Trichodesmium* colonies were not found. It was concluded that the availability of dissolved nitrogen (nitrate + nitrite) in the samples examined precluded the necessity for nitrogen fixation.

On the basis of such findings it is therefore evident that the main problem in the context of the 'carrying capacity' issue is the impact of nutrient loading from the fish farms. The results of Project 9 show that elevated levels of ammonium in surface waters in the immediate vicinity of the fish farms declined sharply towards the west and south. This would indicate that the nutrients from the fish farms are absorbed rapidly by the phytoplankton within a short distance from the farms.

The critical question is then the fate of the organisms (and the detritus derived from these organisms) that have developed from and accumulated the nutrients from the fish farms: *Are this particulate organic matter and the nutrients derived from its decomposition retained in the northern GOA, or are these particulate and organic materials mixed widely into the main water body of the Gulf?*

Inputs from Projects 6, 8, 9 and 11.
The above question was examined in detail in Project 7 (Reports 7a and 7b) on the basis of the long-term data sets for the GOA. Before discussing the conclusions of this project we highlight below some relevant findings and conclusions of closely related projects:

- Simulations of GOA circulation carried out in Project 6 using a numerical model showed that the horizontal circulation is quite dynamic and variable. In these simulations, the most pronounced feature at depths of 250 and 400 m in the northern GOA was a general southward advection of water. Note that the model was forced with monthly mean climatological wind stress, heat flux and salinity flux at the surface. This may mask the full impact of the short term temporal variability of the forcing on the circulation, but such effects are limited primarily to the upper thermocline (i.e. from the surface to a depth of ~ 250m). The other area that this shortcoming can affect is the absence of extreme, deep mixing events which generally depend upon anomalously cold atmospheric conditions. The variability of the absolute speeds calculated may differ from reality; nevertheless, according to the project Principal Investigator these reservations do not change the qualitative picture and the direction of net water transport. It was further concluded that it is rather unlikely that the deep water layer (below 400-500 m) is stagnant.

- The estimates of the release of nutrients from sediments in the northern GOA performed in Project 8, indicated that the flux of nitrogen from the sediments constitutes only a small fraction (~ 2.5 – 15%) of the increase in the water column nitrate inventory during the stratification period, implying that most of the nutrient remineralization (oxidation of particulate organic matter) takes place within the water column. The release of nutrients from the sediments was assessed using two methods: a) Direct measurements (sediment cores incubation experiments) as recommended by the IET; b) analysis of pore water nutrient profiles as the basis of appropriate calculations. The results of the direct measurements imply that the nutrient flux from the sediments contributes only ~ 2.5% to the increase in the water column nitrate inventory during the stratified period while the results of the pore water analysis imply a contribution of ~ 15%. The letter estimate is in agreement with the results of a previous study (David, 2002) based on analysis of deep water nitrate profiles. Note however, that the estimates based on pore water analyses and deep water nutrient gradients involved various assumptions (e.g. values of diffusion coefficients) that were not necessary in the case of the direct measurements. The incubation of a sediment core from a depth of 56 m (near the fish farms) yielded essentially the same nutrient fluxes and N:P ratios (14-18) measured in cores taken at depths of 300 and 600 m.

- The continued nutrient measurements carried out in Project 9 until April 2004 showed a gradual build-up of the deep water nitrate reservoir in the northern GOA after the deep mixing event of 2000 until it reached the pre-mixing values.

- The measurements of total P, organic-bound P, calcium-bound P and organic carbon in surficial sediments of the northern GOA (Project 11) showed a general trend of increase of all parameters towards deep water. Within the sediments the organic –P fraction decreased towards the top layer. High P enrichment in the sediments was attributed mainly to deposition of dust contaminated with phosphate-ore and not to organic-bound P. Very crude mass balance calculations suggested that significant amounts of phosphate-ore dust introduced into the northern GOA were transported by currents southwards.

Are the nutrients from fish farming accumulating in the northern GOA?
As recommended by the IET, the objective of Project 7 (Reports 7a by Lazar & Erez and 7b by Herut & Cohen) was to analyze all the existing oceanographic data sets for the GOA in order to clarify seasonal changes and long-term trends in nutrient budgets. For this purpose, both analyses used the IUI Chemical Data Base prepared by Lazar and Erez within the framework of Project 7. The bulk of this data base comprises of nutrient and dissolved oxygen data from Station A in the northern GOA collected during 1975 – 2004. Data analysis in both 7a and 7b reports focused on Station A as a representative site for the status of the northern GOA.

Both 7a and 7b studies also examined nutrients, oxygen and ancillary data from cruises along the entire GOA. Note, however, that the two reports examined data from different cruises: Four data sets exist - DCPE cruises (1975 – 1977); Tiran II cruise (1982); IUI-Egypt cruise (1992); R/V Meteor cruise (1999). Study 7a compared the 1975 – 1977, 1992 and 1999 data, while study 7b compared the 1982 and 1999 data. No explanation was provided for ignoring the 1982 data in 7a analysis. The 1992 data were not used in the 7b study because they were not included in the IUI Data Base, while the 1975-1977 data were discarded because the analysis of nitrate data from repeated sampling of one station on consecutive days showed large variability in the results.

The reports of projects 7a and 7b (as well as the report for Project 8) include various mass-balance calculations for nutrients in the northern GOA. In both reports, the area considered in the mass- balance calculations for the assessment of possible impact of the nutrient loading from the fish farms, extends from the tip of the GOA to 25 km southwards

(~ Station B1 + 5 km). However, different values were used as estimates of the volume of deep water (> 500 m) and for the surface area of the sediments in the area selected. Our opinion is that the best values to be used for mass-balance calculations are those calculated by the POM Model on the basis of the high-resolution digital bathymetry data of the Geological Survey of Israel (see Section 2.2 in the report for Project 6). A Table of these values is attached (Appendix 1).

On the basis of analysis of the long-term record of nutrient and dissolved oxygen data for Station A, plus the data from the cruises along the GOA and additional information, calculated nutrient and oxygen inventories and N:P ratios for Station A and mass-balance calculations, study 7a concluded that: a) The nutrient content of the northern GOA has increased from the mid-1970's to the present. b) Most of this change (in particular the nitrate change) occurred between 1998 and 1999. c) The nutrient emissions from the fish farms since 1992 are consistent with the increase of the nutrient inventories in the northern GOA and are most probably responsible for this increase.

In contrast, on the basis of a similar analysis of the nutrient and oxygen data, calculated nutrient inventories etc., study 7b arrived at opposite conclusions: a) The apparent increase in the nitrate content of the northern GOA between 1998 and 1999 was not real but derived from erroneous nitrate data for the period 1997 – January 1999 (the actual deep water nitrate concentrations must have been higher than those recorded). b) The variability of the nutrient inventories in the northern GOA during the period of the fish farms operation does not indicate accumulation of nitrogen from the fish farms; c) Much of the long-term variability of the nutrient concentrations in the deep water of the GOA may be due to fluctuations in the hydrodynamics of the Gulf.

During a discussion of the two reports on 27 June 2004[3], one of the Principal Investigators of Project 7a agreed that the deep water nitrate data from Station A for the period 1997 – January 1999 were in error. He stated, however, that considering the rest of the data examined, this error does not change the general conclusions of study 7a.

In summary, one is facing two disparate answers with regard to the fate of the nutrients emitted by the fish farms:

The conclusions of study 7a imply that a substantial fraction of such nutrients is retained in the northern GOA whereas the conclusions of study 7b imply that these nutrients are mixed into the larger water body of the Gulf.

Y. Cohen's (Y.C.) and M.Ottolenghi's (M.O.) conclusions:

Y.C.:
Cohen was a co-author of Report 7b. After reviewing all relevant results of the IET program, his position remains that the available data and information does not indicate a significant impact of the fish farms on the nutrient budget of the northern GOA.

[3] PI's of the IET Program, one of the PI's of study 7a, the PI's of study 7b and several additional scientists were present; the reports of studies 7a and 7b were distributed 6 days in advance of the meeting to allow time for revisions before submission of final versions.

M.O.:
The presently accumulated nutrient data are incomplete and controversial with respect to the pre-1999 events. Nevertheless, they are well accepted in describing the situation since 1999, especially the drop in the nitrogen inventory following the deep mixing in 2000 and its gradual increase to the currently high, 2003/4, levels. At present no clear answer is available as to the exact relative contributions of natural and anthropogenic (mainly fish farming) causes to this (and probably also previous) inventory rise. Still, there are several points supporting the suggestion that the fish farms may contribute substantially to the observed accumulation of nutrients in the northern tip of the Gulf:

(i) The claim in Report 7a that the 1975 -1979 DCPE data obtained prior to fish farming and substantial sewer discharge, show a natural gradient of increasing nutrients towards the south, while the 1999 Meteor data reveal a reversal of this gradient. This effect may be accounted for by a major nutrient source in the north. Note that this argument is valid only if: 1.The 1982 data are discarded. 2. The criticism of 7b with respect to the 1975-1979 data is not taken into account (see discussion above).
(ii) According to study 7a present oxygen concentrations in deep waters have reached unprecedented low values with respect to the 1970's, with no corresponding long term change in water temperature (Project 12).
(iii) The claim (report 7a) that the N:P ratio increased during the end of the 1990's from about 12 to 18. Subject to an analysis that will omit the erroneous 1997-1998 data and to a study of the expected related changes in phytoplankton populations, this may suggest the addition of a nutrient source with a high N:P ratio, such as the fish farms.
(iv) Assuming a dilution pool under the area up to Station B1 + 5km, study 7a claims that a substantial fraction of the annual increase in nutrients after 2000 can be accounted by the annual N release from the fish farms. *Obviously this criterion has to face the (critical) test of extending the nutrient inventory measurements to cover a pool of at least 20 – 40km to the south of station B.*
(v) A key argument in the analysis and conclusions presented in study 7b, based on Project 6, is that a net north to south water transport takes place, effectively competing with the transport of particulate organic matter to the bottom layers. It should be pointed out that no quantitative analysis of these competing processes has been carried out in Project 6. Moreover, the model data should be accompanied by complementary experimental verifications. Thus, the qualitative nature of the present model predictions cannot provide a basis for the claim that the fish farms nutrient output is diluted all the way south, yielding a non-significant nutrient enrichment in the north.

A comment (M.O.'s): The IET recommendations program has markedly increased our understanding of the problems underlying nutrient dynamics in the GOA. Although the main controversy with respect to nutrient accumulation in the North (and consequently the related estimate of the "Carrying Capacity of the Gulf") are still unresolved, the answers are not out of reach. Given the presently available oceanographic methodologies and subject to collaborative work with the neighboring countries, we should be able to provide, within a reasonable timetable, reliable estimates of the contribution of fish farming to the nutrient inventory in the northern GOA.

III.2 Fish Pathogens and Organic and Metal Pollutants

Project 22: Fish pathogens
In recent years, an increase in the prevalence of infections and diseases in wild fish populations in the northern GOA has been perceived. The IET examined the relevant information that was available at the time and recommended that "*the monitoring of fish diseases in the Gulf of Eilat continues, considering not only the fish-farms as potential reservoirs for bacteria but also taking into account the potential long-term changes in susceptibility for diseases with climate change*".

Project 22 designed in response to the IET recommendation, has been the most comprehensive effort to date to investigate the causes of mortality and the prevalence of infectious diseases in wild fish communities along the Israeli GOA coastline (more than 1500 cultured and wild fish were examined). The following conclusions are literally extracted from the Report:

"The data generated in the present study indicate that basically four fish pathogens - three bacterial species (*Mycobacterium marinum*, *Streptococcus iniae, Lactococcus garvieae*) and a myxosporean parasite (*Enteromyxum leei*) - are involved in wild fish mortalities in the Gulf of Eilat. Some additional mortality was apparently due to *Vibrio* spp. and one case was suspected due to human enteric bacteria. Several other mortality cases were attributed to anthropogenic activities, mostly fishing.

The detection of *M. marinum*, *S. iniae, L. garvieae* and *E. leei* over a period of a few years in wild fish populations in the northern Red Sea is worrisome. While all four may be native to the Red Sea, these microorganisms are "new" to the region. Comprehensive ichthyopathological studies conducted in fish cultured in Eilat in the last 30-35 years failed to detect these disease agents, suggesting that either a surge in their virulence has occurred or their appearance is the result of recent introduction. In fact, the available evidence suggests that *S. iniae* and *E. leei* are likely introductions into the Gulf, possibly through transfer of aquaculture stocks. The origins of *M. marinum* and *L. garvieae* are impossible to determine and remain controversial. The appearance of these fish pathogens in the Gulf of Eilat is consistent with an emerging trend affecting marine organisms at a global level in areas subjected to intense anthropogenic impact. It should also be noted that the worldwide distribution of marine microorganisms is changing rapidly, possibly due to global movement of ballast water by ships. This mechanism has been shown to disperse human pathogens over long-distances, and may have significance in impacting marine organisms as well (Ruiz et al., 2000).

From our data it may be concluded that disease-related mortalities of fish in the Gulf of Eilat have been occurring, but do not appear to be a large scale phenomenon. This perception, however, may change with evaluation of new data. It should be kept in mind that our survey was limited in both time and space; samples were collected during daytime, mostly in shallow, inshore waters, and disease debilitated fish are rapidly predated. The scientific evidence produced by this study also shows that morbidities and mortalities in the Gulf resulting from dispersal of fish pathogens from the cage farms, however not negligible, are less alarming than previously suspected. As fish diseases have an inclination to "emerge" suddenly, monitoring them on a permanent basis is not only necessary to maintain an updated, current knowledge of the fish health situation in both farm stocks and wild fish populations in the Gulf, but it is also essential for proper management of our coastal ecosystems. This is particularly true in view of the paucity of comparable scientific data available from neighboring Red Sea countries".

We (Y.C. and M.O.) note that the the IET highlighted the need to study the level of infestation by *Mycobacteriosis* in wild fish (*M. marinum*) and, therefore, present here the main findings of Project 22 regarding the distribution of infections (% of fish sampled): the two localities with the highest prevalence of *M. marinum* infections were, the Underwater Observatory-IUI site (31%) located in the southern part of the coral reserve, and the fish farms (13%). These sites were previously considered "hot spots" with regard to *M. marinum* infections. About 7% prevalence of *M. marinum* infections was found at one site in the North Beach area but no infected fish were found at two nearby sites. About 7% prevalence of *M. marinum* infection was found in Taba, near the Egyptian border.

Following are personal opinions of M.O. and Y.C. with respect to the fish disease issue:

M.O.:

- In spite of the relatively low levels of infestation to date and independently of the unquestionable findings of Project 22, the very presence of high densities of caged fish is a dangerous potential source for amplification of injection and spread of diseases.
- The above position is not based on a quantitative risk analysis, but rather on the unpredictability of disease evolution and spreading.

Y.C.:

- Project 22 revealed that the actual situation in the northern GOA with regard to fish diseases is very different from common perception and less alarming then previously suspected. Further risk assessment should be based on hard data and scientific principles.

Project B2: Metal and organic pollutants

Monitoring of metal and organic pollutants along the Israeli coastline of the GOA was added to the IET program in order to expand the basis for comprehensive assessment of potential environmental problems in the area.

Project B2 examined the distribution of heavy metals and various organic pollutants in coastal waters and sediments. The results of sampling carried out within the framework of the IET Program were presented together with additional data collected by IOLR during 2002/3. The analyses were performed by certified/qualified laboratories in Israel and the USA using validated procedures.

High levels of metals (mainly Mercury, Copper, Lead, Cadmium and Zinc) and organic pollutants (PCB's, DDT and TBT and its degradation products) were found in the sediments at several "hot spots" along the coast, mainly within marine structures. At the Eilat and Navy ports and at the Tur-Yam (South Beach) and Eilat (North Beach) marinas, the concentrations of some metals in the surficail sediments exceeded levels that can potentially induce toxic effects in marine organisms (adopted as sediment quality guidelines by the US National Oceanic and Atmospheric Administration). At the Eilat and Navy ports the concentrations of PCB's exceeded the sediment quality guidelines.

Relatively high PCB's levels were also found at the Tur-Yam Marina. At the Navy Port and a site near the Eilat Port the concentrations of DDT exceeded the sediment quality guidelines.

The most alarming finding was the presence high levels of tributyl-tin (TBT) in the coastal waters and sediments at several sites. TBT used in antifouling paints is considered *the most toxic substance ever introduced intentionally into the marine environment*. Adverse effects of TBT on a wide range of marine organisms had been documented worldwide, even at very low levels of exposure. Such effects include inhibition of coral fertilization and larval metamorphosis.

High levels of TBT in the sediments were found at the Eilat and Navy ports and at the Eilat and Tur-Yam marinas. At the Eilat and Navy ports the TBT concentrations measured in seawater samples exceeded by far the Seawater Quality Criteria of the US EPA (also adopted by the Israeli Ministry of Environment on an interim basis). The concentration ratios of TBT and its degradation products in both the sediments and water samples indicated continued TBT input.

The overall conclusion of the project was that *various metals and organic substances are present along the Israeli GOA coastline at concentrations well above levels at which toxicity may begin to be observed in sensitive species*.

Project B1: Detergents

Project B1 examined the distribution of anionic and cationic detergents along the Israeli GOA coastline. A few of the seawater samples were analyzed by two laboratories and the results were found to be in good agreement. Repeated measurements during 18 months revealed high concentrations of both groups of detergents in shallow waters all along the coastline. Most concentrations measured exceeded international seawater quality criteria as well as the temporary criteria adopted by the Israeli Ministry of Environment. Furthermore, the detergent concentrations measured at most of the coastal water samples were significantly higher than those measured at Station A (open water, a few km from the coast). These findings are potentially alarming as detergents are known to be harmful to marine organisms and ecosystems (some harmful effects of detergents on clams and phytoplankton were also indicated in very preliminary experiments performed as part of Project B2).

In our opinion several findings require further clarification:

- The relatively uniform distribution of detergent concentrations all along the coast on most sampling occasions.
- The levels of detergents measured at Station A were not negligible. Also, sampling that showed high values in the shallow water stations were not accompanied by analogous measurements at station A.
- The study lacks the analysis of deep water layers at station A.

We think that further validation of the adequacy of the sampling and analytical procedures is required. Extension of measurements to deep water at Stations A <u>and B</u> is also recommended. In our opinion, at this stage, definite conclusions would be premature.

III.3. Biological/Ecosystem Investigations

The IET report stated:
"*There is universal agreement that the water clarity and the coral reefs of the Israeli territorial waters in the Gulf of Eilat are deteriorating. The Israeli territorial waters apparently suffer from lost diversity (50%), decrease in coral cover (50%), low rate of coral-larval settlement and recruitment, decreased rates of coral reef calcification, recent coral mortality and increasingly intense macro-algal bloom during spring…*".
Thus (with the exception of the topic of coral recruitment - IET Recommendation 18) the IET recommendations focused on seeking explanations for the above ecological changes rather than quantifying the related phenomena.

Nevertheless, following suggestions from a number of scientists it was agreed to include in the Program a section (#16) dealing with the application of specific methodologies for evaluating coral reef metabolic parameters and establishing stress indicators. The original work-plan spanned the issue from the "community level" (Project 16a – calcification, photosynthesis and respiration), through the "colony level" (Project 16b – irradiance, and submersible respirometry), to the "cellular level" (Project 16c - cellular and molecular biomarkers as anthropogenic stress indicators). These projects, funded through other programs, were contributed by the Principal Investigators to the IET Program at no additional cost. Unfortunately, due to experimental difficulties Project 16b was not carried out to completion.

Below we briefly address the work performed in Projects 18, 16a, and 16c and the related conclusions. We also include in this section the conclusion of project 12 that examined the long-term temperature record for the GOA. The IET recommended this activity in order to determine whether there are increasing temperature trends that may enhance coral bleaching.

We wish to emphasize that this report *neither discusse*s *the biological studies carried out in recent years in relation to the apparent deterioration of the coral reefs in the northern GOA, nor enters the ongoing debate in the scientific literature on the effects of nutrient enrichment on reef-building corals and coral reef ecosystems.* On these issues we make reference to independent publications, such as recent articles by Abelson, Chadwick-Furman, Dubinsky, Loya, Rinkevich, & respective coworkers, and references cited therein.

Project 18: Coral recruitment
The objective of Project 18 was to monitor the recruitment rate of corals along the Israeli GOA coastline, including sites near the fish farms as recommended by the IET. The work - plan originally aimed at a series of systematic studies of coral recruitment onto artificial substrates (settlement plates). However, this task was performed only once during the two year period of the IET program (in Sept.–Oct. 2002). Consequently, the submitted Report 18 is primarily a non-comprehensive discussion of a collection of previous studies carried out over the last seven years.

In our opinion the report does not advance our understanding of coral recruitment in the GOA because of several reasons:
(1) The lack of critical methodological details that interfered with comprehension of important parts of the manuscript.

(2) The inconsistencies with the analysis of the spatial and temporal scales of variations in coral recruitment processes along the Eilat coast, as presented by Glassom et al (Mar. Biol. 144: 641-651, 2004). [In our opinion, the different conclusions of the two studies regarding the scales and possible causes of the variability of coral recruitment, as well as its absolute rates, should be analyzed in depth before drawing conclusions].

(3) The scarcity of new data.

Project 16a: Metabolic studies in the coral reef – community metabolism

Project 16a sought to relate temporal changes in metabolic processes (calcification, photosynthesis and respiration) in the Eilat Nature Reserve Reef (NRR) with changes in the live coral coverage and environmental conditions (in particular the nutrient content of the seawater flushing the reef). Information on these processes was derived from continuous measurements of physical and chemical parameters in the NRR lagoon. The results were combined with those of previous studies to examine long-term trends. The main conclusions of the project were:

1) Community calcification in the NRR has decreased by a factor of ~ 2 during the period 1990 – 2003. This was attributed mainly to three factors: (i) Reduction of live coral cover by more then 50%, in good agreement with direct coral cover studies in the NRR. (ii) Increase in nutrients (mainly nitrate+nitrite) in the open seawater that are flushing the reef. (iii) A continued growth of macroalgae that overgrow the corals and prevent larval recruitment and standing stocks replenishment.
2) Coral calcification (G) is positively correlated with the chemical saturation of aragonite (Ω_{arag}) deposited by the corals. The dependence of G on Ω_{arag} is suppressed under high nutrient levels in the water flushing the reef.
3) Since 2002 live coral cover in the NRR have decrease by an additional ~ 7% relative to the period 1997 – 2002.
4) Dissolution events during 2003/4 have become significantly more frequent than during the previous two years.
5) Dissolved oxygen data from the NRR for the last three years indicates exposure of the reef to continued external nutrient loading. Very low oxygen concentrations observed during July 2003 were likely associated with an increased load of organic matter from the open sea. This is very unlikely to occur naturally during that season.

We believe that the conclusions suggested in the study should be reconsidered on the basis of the following arguments:

(i) The underlying assumption of the study is that the reef lagoon, where the measurements were performed, is a representative site for the state of the NRR. However, it is well established that the Eilat coral reef exhibits high variability of ecological parameters within short distances. Certainly there are major differences in both coral community structure and coral biomass between the NRR lagoon, the reef flat and the fore reef, where coral growth is the densest.

(ii) In the same context, the two papers cited in study16a, reporting a ~ 50% decrease in live coral cover at the NRR (Zakai, 2000; Loya 2004) refer to surveys carried out in the reef flat and the fore reef areas (depths of 4 -12 m) rather than in the lagoon. We also note that the paper by Zakai reports a > 40% decrease in live coral cover between 1996 and 1999 rather than, as claimed, between 1990 and 2003.

(iii) In the NRR lagoon itself, repeated annual surveys of *Stylophora* colonies carried out at the IUI from 1996 to 2004, revealed a gradual, almost 4-fold increase in colony density (colonies/ m^2) between 1996 and 2002 and stability since then (report by A. Genin to the Nature and Parks Authority, 7 June, 2004).

In our opinion the above points must be clarified. Thus, at this stage, definite conclusions from Project 16a would be premature.

Project 16c: Metabolic parameters in the coral reef – cellular-level biomarkers for stress

This project constitutes a pioneering attempt to use cytologic/genotoxic parameters for assessment of stress symptoms in two species of stony corals (*Stylophora pistillata, Pocillopora damicornis*) from various sites along the Israeli GOA coastline. The parameters chosen were: Micronucleus frequency - MNT); DNA breakage – DNA-br (acidic DNA unwinding assay); Esterase activity (EA).

The main conclusion of the study is that on the basis of all three parameters examined, the two most disturbed sites along the coast were the North Beach and the Ports area: at these sites there were strong agents which disrupt cell functions and cause genotoxic responses in organisms. It was noted that the results of the project do not show causality and cannot pinpoint the exact agents responsible for the observed stress symptoms.

Another conclusion, which was not an outcome of the project, claims that a compilation of various studies based on other organisms, strongly suggest that the major pollution hotspot in the north beach is the fish-cage area.

We wish to make the following comments, expressing our reservations with respect to this project and its conclusions:

a) While alkaline DNA – unwinding is commonly used, the acidic method described in this work is seldom employed, and then exclusively in mammalian systems. Further studies should validate this method in marine invertebrates and, specifically, in corals.

b) The effectiveness of the coral model with respect to EA inhibition by chemical pollutants in the marine environment remains to be established. In fact, the project report states explicitly that it lacks *"analytical baselines which provide dose-response curves*". We think that the arguments provided for the validity of the methods used despite of this problem, are insufficient.

c) Although all 3 methods yield a general North to South trend of decreasing stress symptoms, the behavior in the case of the DNA test (Fig.3 – sudden jumps at St. 4 and 12 and gradual changes from St. 4 to 10 and from St. 12 to 16) indicates the presence of specific hot spots that are not revealed by the MNT and EA data.
It should also be noted that the North to South trend is indicative of disturbances in the North but it was not carried out on a (high resolution) scale that could test the evolution of the effect from the fish cages as point zero.

d) We note that the results of project 16c are expected to correlate with those of Project B2, which detected "hot spots" of metal and organic pollution along the coast of Eilat. It is reasonable to assume that DNA damage and EA inhibition are likely responses to at least some of the contaminants found in theses "hot spots". No such correlation is observed (e.g. the results for the highly polluted Tur-Yam Marina by MNT versus those for clean sites).

e) The second conclusion of Report 16c, pointing at the fish-cages as "... *the major pollution hotspot in the North Beach…*" is questionable. This conclusions is derived from previous studies by the same investigators (Bresler et al, 1999; 2003) that used the same methods in molluscs. Our principal criticism concerns the argument claiming the presence in the vicinity of the fish farms, of *"certain genotoxic and clastogenic pollutants in the studied environment,* ***probably nitrosoamines****"* (bold emphasis is ours). No supporting evidence whatsoever was given for the nitrosoamine hypothesis. (For example, information on the nitrosamines species and amounts, their possible mechanism of formation, reports of independently detected nitrosamines from fish waste in a marine environments, etc).

Project 12: Analysis of water temperature variability in the GOA

Project 12 examined all available temperature data from the GOA that was available in the IUI Chemical Data Base and CTD Data Base (1975 – 2003). After quality control and rejection of incorrect and suspicious data, the remaining data for the northern GOA were interpolated to standard levels. The 50 db level was selected for estimation of long-term temperature tendencies in the upper layer of the water column. Trend analyses were performed for the entire data set and then separately, for the winter and the summer measurements.

The conclusion of the project was that the temperature of the upper layer in the northern GOA does not exhibit any significant long-term tendencies.

III.4 Critical (future) research and monitoring activities

Regardless of any decisions that might be taken in the short-term concerning existing activities and development plans in the northern GOA, it is our opinion that the outcome of the IET program clearly points at the need for several critical research and monitoring activities. We recommend the following high priority activities that will address the major open questions, in support of the overall environmental management of the Gulf:

1. Monitoring whole water column nutrient and oxygen concentrations as far south as possible from Station B1, aiming at producing 3 dimensional distribution maps. This will allow addressing the key question as to the accumulation of nutrients in the northern part of the Gulf.
2. Current measurements and inert tracer experiments to verify hydrodynamic model predictions and to provide direct information on intermediate and deep water transport patterns and the residence time of the deep water in the northern GOA.
3. Routine monitoring of fish disease. As fish diseases have inclination to "emerge" suddenly, monitoring them on a permanent basis is essential in order to maintain updated knowledge of the fish health situation in both farmed stocks and wild fish populations.
4. Routine (annual) monitoring of metal and organic pollutants along the Eilat coastline as a basis for decisions on prevention measures and evaluation of their effectiveness.

5. Surveys of detergents along the Eilat coastline (after validation of the procedures involved) and should the results turn out alarming - permanent monitoring of these compounds.

In the longer term, it would be highly desirable to develop a coupled hydrodynamic-ecological modeling system for the GOA as a major support tool for decisions on development plans and environmental management programs.

Appendix 1.

Calculated volumes and surface areas of various areas in the northern GOA.

Examples: Volume of *layer 500-bottom* at *Station B1+5* = the volume of water deeper than 500 m in an area extending from the tip of the GOA until 5 km south of Station B1. Area at *depth 300* at *Station B1+5* = the surface area at water depth of 300 m in the above area.

Values calculated by S. Brenner using POM Model with high-resolution digital bathymetry data provided by the Geological Survey of Israel

		Volume	(km**3)				Area	(km**2)	
Location	Sta A	Sta B1	**Sta B1+5**	Sta B1+10		Sta A	Sta B1	**Sta B1+5**	Sta B1+10
layer					depth				
0-300	9.1931	32.1419	**45.9611**	61.6945	0	44.1508	137.1922	**192.0737**	253.3428
300-bottom	4.8421	30.095	**48.1303**	69.8689	300	20.9168	85.688	**125.7076**	171.57
400-bottom	2.981	22.0349	**36.2143**	53.5007	400	16.2691	75.5828	**112.8281**	155.9134
500-bottom	1.5981	15.0372	**25.6384**	38.7497	500	11.7102	64.4026	**98.8716**	139.1798
600-bottom	0.6284	9.2142	**16.4862**	25.6961					
700-bottom	0.1045	4.7002	**8.8707**	14.5132					
800-bottom	0.0158	1.4324	**2.944**	5.5286					
900-bottom		0.0588	**0.2049**	0.585					
0-bottom	14.0353	62.2369	**94.0914**	131.5633					