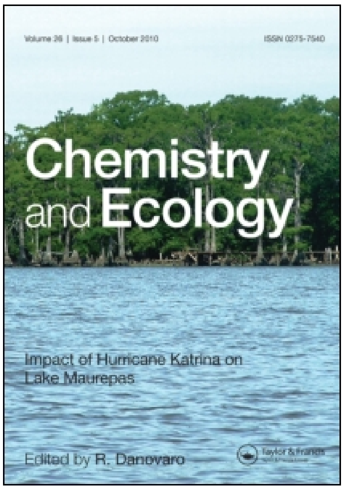

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The Environmental Capacity Approach to the Control of Marine Pollution: The Case of Copper in the Krka River Estuary

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The Krka River estuary (Yugoslav Eastern Adriatic region near the town of Šibenik) with its Prokljan basin, and copper as water contaminant) is used to model a management strategy based on the environmental (assimilative, absorptive, receiving) capacity. This estuarine region is faced with conflicting land and sea use activities, such as mariculture for salmonids, and mooring of pleasure boats and yachting. All these activities in the Prokljan region are additional to industrial effluents originating from the industrial town of Knin, and in the particular case of copper, land-based run-off from vineyards. The present level of total contaminant load is still not excessive, but the potential of the estuarine basin for mariculture requires anticipatory restrictions which depend on the extent and nature of activities to be accommodated.

The calculation of environmental capacity and the ensuing conclusions are based on the available information on hydrology, physical, chemical and sedimentological processes, and the establishment of a mass balance model. The biogeochemical fate of pollutants is considered in terms of restrictions imposed. In this paper the approach is exemplified for a single pollutant, copper, which, under prevailing conditions, appears to be the most critical in endangering mariculture activities. Restrictions should be imposed on new activities such as the use of copper-based antifouling paints on boats and yachts entering and mooring in the Prokljan basin.

Use of the environmental capacity principle for advising regulation of activities, in this case the creation and expansion of a mooring facility (marina), is discussed. The conclusion is reached that a limit must be imposed on the number of boats present at the same time in the area, and that this number is significantly less than that represented by simple physical accommodation capacity for boats.

KEY WORDS Contaminant load; Mariculture; Hydrology

INTRODUCTION

Prevention of pollution of marine areas requires an administrative approach usually called *strategy*. The best known strategy is the uniform emission standard (UES) practiced in most countries of the European Economic Community (EEC, 1976). The Protocol on the Land-based Souces of Pollution to the Barcelona Convention of the Mediterranean countries relies on the Black/Grey list approach. In contrast, the prevailing strategy used in the United Kingdom is that of the Environmental Quality Objectives, by which a set of environmental parameters, mostly for improving present conditions, is defined and implemented through various measures. Either of these approaches can fall short of stated aims, when the requirements for water quality are high, while the region is already being loaded by urban, agricultural and sewage run-off from activities outside the investigated area. The environmental capacity approach (GESAMP, 1986) is an interactive, anticipatory strategy, based on the determination of the ability of the ecosystem to accommodate activities and receive waste products without deterioration, i.e. without suffering pollution. The term *pollution* is used in the sense of prevailing definitions (Tomczak, 1984), but mainly that of GESAMP.

DETERMINATION OF ENVIRONMENTAL CAPACITY

The essence of the exercise to determine the environmental capacity of a particular area involves several steps. These are:

(a) geographical description of the area including delineation in terms of hydrology;

(b) identification of the critical target in need of protection; normally it will be either the most sensitive or the most valuable (in ethical, social, or economic sense) species;

(c) identification of one or more critical contaminants, for which there is scientific evidence that it can cause damage, i.e. pollution (in the sense of GESAMP's definition);

(d) setting and acceptance of water quality criteria, and standards (which are legislated);

(e) setting of a mass balance, or, if needed, a higher ecological or environmental model; and

(f) recommendation on the basis of scientific assessment, which can be translated into a decision on the use, apportionment of capacity available and protection of the target or amenity.

The delineation of the impacted area is a major problem if the case involves an open coast and shelf. In semi-enclosed or enclosed basins the delineation is more straightforward.

Identification of the critical target follows considerations of economic, ethical or social values; however, the ecosystem has to be understood in that the protection of the critical target will also protect the quality of the entire ecosystem.

The approach based on a single contaminant is simple, whereas the case of multiple contaminants (e.g. in urban sewage) will require additional information and management decisions; for example is it advisable to use the simple additivity principle or incorporate synergistic or compensatory/antagonistic effects?

In setting standards of quality, criteria must be based primarily on environmental and toxicological data. However, non-scientific inputs, such as policy decisions and economic considerations will usually be incorporated.

The determination of the environmental capacity requires use of a model. For many purposes a simple mass balance model is sufficient. Any uncertainties can be accommodated by some safety factor (EEC, 1976), or, in terms of toxicology, an application factor (Lloyd, 1979). There will rarely, if ever, be sufficient data available to encompass the complexity and variability of biological or environmental systems. However, the missing data can often be approximated from experience elsewhere; useful compendia exist for this purpose (WHO, 1982; EIFAC, 1983). Alternatively, the probabilistic approach can be used (GESAMP, 1986). The major transport processes often exert a greater influence on the accuracy of the model than refinements based on the retention of the contaminant in the biological cycle, so transport factors deserve most attention and should be most accurate.

More advanced modelling requires refinements based on more, and more reliable, data which, in turn, imposes strict quality assurance. Consequently, any decision making in a framework of uncertainties must be based on a rational approach to an acceptable level of a priori risk assessment.

As stated, the end points of tolerable concentrations of the contaminant(s) will depend on the water quality criteria and standards defined. Accordingly, the model will have to be chosen at different levels, commensurate with data available, the required level of risk acceptance, and the importance of the target. In general the following levels of modelling of progressive complexity can be used in the determination of environmental capacity:

Level 1. Models based on hydrodynamic data. For example, in an estuarine area the flushing rate determines the mean residence time of a conservative contaminant. One of the major problems is to assess the probable error involved in averaging the varying flow rates. If this variation is large, such as is the case in many southern European estuaries, then a model based on hydrodynamics alone will be as good as a more sophisticated one.

Level 2. Hydrodynamics combined with suspended matter transport and sedimentation. Considerations follow from Level 1., above, assuming that a variation in flow rates of water is accompanied by a large increase of remobilization of particulate matter; or vice versa so that at minimal flow rates, sedimentation will prevail as the dominant mode of contaminant removal from water.

Level 3/Sublevel 3a. A Level 2 model is improved by data on biological activity, including phyto- and zooplankton cycles. The removal of the contaminant through faecal pellets of zooplankton can be included in the total sedimentation rate in Level 2. The amount of contaminant cycling in the biotic part of the estuary can be expressed by a factor in the mean residence time.

Level 3/Sublevel 3b. Instead of biocycle considerations, as explained above, Level 2 is refined by inclusion of physico-chemical processes, chemical reactivity and transformation, contaminant binding into biologically more or less active forms (i.e. changes in bioavailability), and the enhancement of toxicity by either partial oxidation (e.g. polyaromatic hydrocarbons) or reduction (e.g. methylmercury, or various forms of organotin).

Level 4. A comprehensive model incorporating both Sublevels 3a and 3b. Such a model requires an interaction matrix of considerable complexity, which can be built only on a wealth of reliable data.

In most cases, particularly in estuarine areas, e.g. the Northern

Mediterranean coast, the variation in flow rates is such that this will outweigh in significance the biological and chemical components of contaminant cycling. In all these considerations, explicit definitions of assumptions made are necessary. The example which follows illustrates Level 2 modeling.

CASE STUDY

The area studied is the Krka River estuary in the Yugoslav eastern Middle Adriatic region (Figure 1). It can be subdivided into five subareas, determined by geographic and hydrological conditions. It is an estuary cut into the Upper Cretaceous—Eocene limestone erosional plane. In the catchment area there is a subordinate quantity of clastic rocks (Eocene and Quaternary marls and clays) that are the source of particulate material. The Krka River shows large fluctuations of throughput from a low level of 5 m^3/s to about 400 m^3/s (Juračić, 1987).

The estuary is characterized by a strong, well defined thermocline

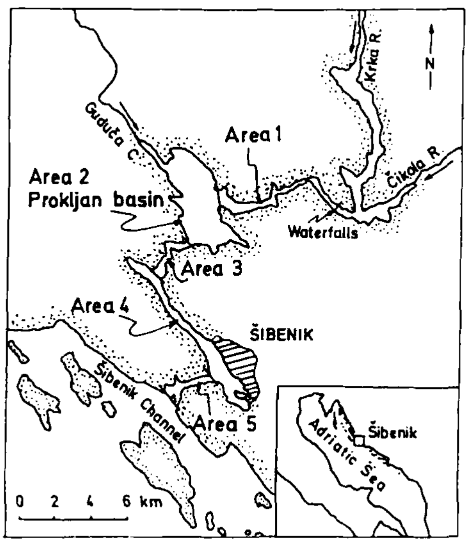

FIGURE 1 Map of the Krka River estuary. Numbers indicate the subareas for hydrological delimitation.

TABLE I
Basic hydrological parameters for subareas of the Krka River estuary, as defined in Figure 1

No.	Area (km^2)	Volume (km^3)	Average salinity in the 3 m thick brackish layer (ppt)
1.	2.1	0.013	2
2.	11.5	0.117	4
3.	0.9	0.021	7
4.	5.5	0.142	18
5.	1.2	0.027	22
Total	21.2	0.320	

and halocline (Nožina and Vučak, 1986). The surface water shows average salinity values from 2 to 22 ppt from area 1 to area 5 (*cf.* Figure 1). The invasion of sea water causes the salinity to be in excess of 35 ppt below the halocline. Both the upper and the lower layer are well mixed. The tide is less than 0.5 m in amplitude, and the basin being well sheltered, there is no major storm induced mixing (Gržetić *et al.*, 1986).

Table I summarizes the volume of the subareas 1 to 5 and corresponding salinity data in the surface brackish layer.

The Prokljan basin has a suspended matter load, originating from the Guduča Creek, with a strong temporal variation, depending on hydrological conditions. The sediments are predominantly carbonate, have a mean size of 7 μm, with a specific surface area of 30 m^2/g, an ion exchange capacity of 10 meq/100 g, relative porosity 40% and a specific density of 1.6 kg/dm^3. Sediments accumulate in a bottom area of approximately 6 km^2, with the average sedimentation rate of 0.12 mm/y (range 0.27 to 0.06 mm/y), or 35 g/s. (Juračić, 1987).

The biological activity in the estuary is typical of the Adriatic Sea and still oligotrophic.

The choice of contaminant for the modelling exercise is a complex decision, involving careful assessment of its origin (Foerstner, 1980; 1983) and toxicity (Hodson *et al.*, 1979; Birge and Black, 1979). In the case study of the Prokljan basin, copper was chosen. In this karstic region, copper is predominantly of anthropogenic origin (Prohić and Juračić, 1988) and its release can, therefore, be regulated. It is a toxicant widely used in antifouling paints. The whole region upstream and downstream is a wine growing area where $CuSO_4$ is still used quite seasonally as a pesticide, and its residuals are washed into the river stream. The metal works of the upstream town of Knin have also been identified as a point source of copper. Data have been collected on its concentration in both fresh and sea water, in suspended matter, and in sediments (Branica *et al.*, 1985; Prohić and Juračić, 1988).

Water quality standards have been established in Yugoslavia for river, lake and basin waters, based on primary scientific literature and the recommendations of WHO and FAO (Government of SR Croatia, 1984). This legislation specifies a concentration of copper of 0.01 mg/dm^3 in waters intended for salmonid aquaculture. The main activity in this estuarine area requiring high quality water is mariculture of salmonids. The juvenile stages of salmonids are sensitive to the presence of many toxicants, particularly copper (Birge and Black, 1979). The choice of this sensitive target organism implies, that other species, constituting the ecological balance of the area, will be protected as well. This assumption must be verified by monitoring, and be open to reassessment. The setting and acceptance of water quality criteria is based on the intention to preserve this activity in the Prokljan basin. The specified value was accepted as the end-point in the calculation of the environmental capacity.

Finally, the aim of this paper is to advise on the total additional amount of copper that can be received by the area from releases of antifouling paints. Most of these paints are still copper based. Little is known about the complex biogeochemical cycle of copper, or of other trace metals such as cadmium or lead, in this specific karstic estuary.

With the data available, the next step was the establishment of a mass balance model, indicated as Level 2 (Figure 2). For the purpose of a preliminary assessment and apportionment of the environmental capacity of the Prokljan basin, it was considered adequate. Monitoring and reassessment activities have been provided within the framework of monitoring programs. The most important additional component in the elaboration of the model to Level 3a will be the incorporation of the primary productivity and zooplankton metabolism of copper, for which there are presently no reliable data.

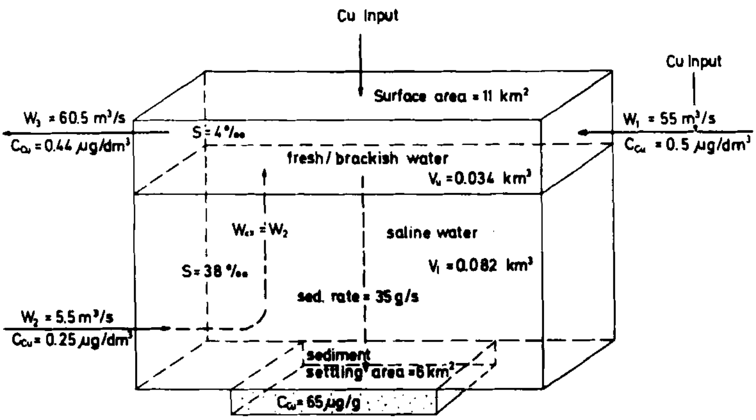

FIGURE 2 Mass balance model (Level 2, see paper) for the Prokljan basin. The model involves water transport, sedimentation and Cu input and output.

It should be stated that additive or synergistic effects of Cu with other possible contaminants have not been taken into account, although some positive evidence exists for these, but at higher concentrations (Birge and Black, 1979). Of the other trace metals, analysis of water and of sediments shows only low concentrations of Hg, nor was Cd identified as a major pollutant threat. The interaction of Cu with organic matter has been considered to produce complexes, resulting in reduced availability of Cu to biota (Sunda *et al.*, 1984).

CALCULATION OF ENVIRONMENTAL CAPACITY

The first step in the calculation of environmental capacity is shown in Table II, where the two compartments, the fresh/brackish upper layer, and the saline lower layer, are separated. The assumptions, based on the available data (Buljan, 1969; Juračić, 1987) are: that there is no mixing between the layers, except a throughput of saline bottom water which penetrates into the upper layer and is drained from the basin, and sedimentation of suspended matter. The calculations are performed for the high, average and low flux conditions of fresh water entering from Subarea 1 (Figure 1).

The calculation considers only the lower, saline compartment, since it retains its water for considerably longer times; the natural

TABLE II
Water transport data for the Prokljan basin

Compartment	throughput (m^3/s) hi	ave	low	mean residence time t_{mr} (days) hi	ave	low	average yearly incidence of throughput (days) hi	ave	low
Upper	440	60.5	5.5	1	7	79	30	230	100
Lower	40	5.5	0.5	24	174	(1900)*			

* Calculated but unrealistic value

rearing habitat of salmonids is predominantly in this compartment. The upper layer is flushed more efficiently, and even with a large Cu input, there will be less copper retained.

The following is the calculation procedure for the determination of environmental capacity of the Prokljan basin for Cu as contaminant, and salmonids as the critical target:

Max. allowable Cu concn. [water quality standard (Government of SR of Croatia, 1984)]:	0.01 mg/dm^3
Volume of the lower compartment	0.082 km^3
Background concn. of Cu in entering saline bottom water:	250 ng/dm^3
Input of Cu by saline bottom water:	1.38 mg/s or 0.12 kg/day
Average sedimentation rate:	35 g/s or 3000 kg/day
Concn. of Cu in suspended matter:	125 ppm
Concn. of Cu in sediments:	65 ppm
Difference attributable to Cu input from suspended matter:	2 mg/s or 0.172 kg/day
Total input of Cu:	3.4 mg/s or 0.29 kg/day

Total cumulative Cu load to the basin at $t_{mr} = 174$ days:	50.6 kg
Resulting background Cu concn.:	0.62 $\mu g/dm^3$
Ultimate usable environmental capacity:	4.7 kg/day
Used environmental capacity:	6.2%
Suggested safety factor due to the uncertain distribution pattern:	0.2 (or only 20% of EC can be safely used)
Calculated environmental capacity for Cu as contaminant, and salmonids as the critical target:	**0.94 kg/day**

Decision Recommendation

Decision recommendations for use of the Prokljan basin as mooring port for pleasure and fishing boats:

It is suggested that only 20% of the environmental capacity be apportioned for this particular use, i.e.:	0.19 kg/day
Approximate leaching rate for Cu based antifouling paints (Goldberg, 1976):	0.1 $g/m^2/day$
Average boat painted area:	10 m^2
Total expected leach rate per boat:	1 g/day

Maximum allowable no. of average boats admitted per day (24 hours residence): **190**

Consequently, if the approach above is accepted, there is a need to limit the number of boats admitted to the area, to safely continue the safe mariculture of salmonids. If the antifouling paints used were to be changed to tributyl tin compounds (US Navy standard is 50 ng/dm^3; UK Water Quality Target is 2 ng/dm^3: Portmann and Lloyd, 1986), a reassessment would be necessary, using new sets of data on toxicity of tributyl tin and leach rates, and new water quality standards.

CONCLUSION

The above example shows the general approach to the use of the strategy of environmental capacity in making management decisions with respect to the multiple use of a marine and coastal area. The concept is based on analytical data and on dynamic principles and represents a continuation of previous ideas and elaboration of the concept (Goldberg, 1979). Any future development or activity in the area must be designed with enough flexibility to enable adaptation to new conditions.

This procedure does not violate the principles of other pollution combating strategies, such as uniform emission standards, maximum allowable concentration, best available technology, or best practicable means available. It advances the appraisal of needs and possibilities for area development a step further, by providing for a rational decision on the maximum permissible extent of contaminating activities in the area, based on well designed research and monitoring projects.

In this sense the environmental capacity approach is an effective means of implementation of the requirements, set out in e.g. Article 7 of the Protocol for the Protection of the Mediterranean Sea against Pollution from Land-based Sources.

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The critical reading and comments given by Dr. Biserka Raspor are highly appreciated.

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References

Birge, W. J. and Black, J. A. (1979). Effects of copper on embryonic and juvenile stages of aquatic animals. In *Copper in the Environment. Part* 2: *Health Effects* (Ed. Nriagu, J. O.) Wiley-Interscience series of texts and monographs: Environmental Science and Technology. John Wiley & Sons, New York, 373–399.

Branica, M., Peharec, Z., Kwokal, Z., and Kozar, S. (1985). Trace metals in the Šibenik aquatorium. *Rapp. Comm. Int. Mer Medit.*, **29** (7), 111–113.

Buljan, M. (1969). Some hydrographic properties of estuarine areas of Krka and Zrmanja rivers (in Croatian, extd. abstract in English). *Krš Jugoslavije* (*Yugoslavian Karst*), **6**, 303–331.

EEC (European Economic Community) (1976). Directive on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community (76/464/EEC). *Official Journal European Community, Legislation,* 19 (*L129*). 13–29.

EIFAC (European Inland Fisheries Advisory Commission) (1983). Revised Report on Fish Toxicity Testing. *EIFAC Tech. paper No.* 24, *Revision 1,* FAO, Rome.

Foerstner, U. (1980). Inorganic pollutants, particularly heavy metals in estuaries. In: *Chemistry and Biogeochemistry of Estuaries* (Eds. E. Olausson and I. Cato), Wiley, 307–348.

Foerstner, U. (1983). Assessment of metal pollution in rivers and estuaries. In: *Applied Environmental Geochemistry* (Ed. I. Thornton), Academic Press, 395–423. A review with 155 ref.

GESAMP (IMO/FAO/Unesco/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution) (1986). Environmental Capacity: An approach to marine pollution prevention. *GESAMP Reports and Studies No.* 30, FAO, Rome.

Goldberg, E. D. (1976). The health of the oceans. The Unesco Press, Paris, 172 p.

Goldberg, E. D. (Ed.) (1979). Assimilative Capacity of US Coastal Waters for Pollutants. *Proc. Workshop Crystal Mountain, WA., USA,* National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Boulder, CO.

Government of SR Croatia (1984). Decree on the maximum allowed concentrations of dangerous substances in waters and the coastal sea. *Narodne novine* (*Official Gazette*) *of the SR of Croatia No.* 2 *of* 24*th January,* p. 7 ff.

Gržetić, Z., Škrivanić, A., and Viličić, D. (1986). Hydrological variability of the river Krka estuary (1984–1986). *Rapp. Comm. Int. Mer. Medit.*, **30** (2), 36.

Hodson, P. V., Borgmann, U., and Shear, H. (1979). Toxicity of copper to aquatic biota. In: *Copper in the Environment. Part* 2: *Health Effects* (Ed. Nriagu, J. O.).

Wiley-Interscience series of texts and monographs: Environmental Science and Technology. John Wiley & Sons, New York, 307–372.

Juračić, M. (1987). Sedimentation pattern in some Adriatic estuaries, properties of recent sediments and suspended matter. Ph.D. Thesis. University of Zagreb, 103 p.

Lloyd, R. (1979). The use of concentration-response relationship in assessing acute fish toxicity data. Analyzing the hazard evaluation process. *American Fisheries Society*, Washington D.C., pp. 58–61.

Nožina, I. and Vučak, Z. (1986). River-sea interaction in the estuaries of major Adriatic rivers (in Croatian). *Gradjevinar* (Zagreb), **38**, 139–145.

Portmann, J. E. and Lloyd, R. (1986). Safe use of the assimilative capacity of the marine environment for waste disposal—Is it feasible? *Water Science and Technology*, **18**, 233–244.

Prohić, E. and Juračić, M. (1988). Heavy metal concentrations in sediments. Problems concerning determination of anthropogenic influence. *Environmental Geology and Water Sciences*, (in press).

Sunda, W. G., Klaveness, D., and Palumbo, A. V. (1984). Bioassay of cupric ion activity and copper complexation. In: *Complexation of Trace Metals in Natural Waters* (Kramer, C. J. M. and Duinker, J. C., editors). Martinus Nijhoff/Dr. W. Junk Publishers. The Hague, 393–409.

Tomczak, M. (1984). Defining marine pollution. *Marine Policy*, **8**, 311–322.

WHO (World Health Organization) (1982). Rapid assessment of sources of air, water, and land pollution, *WHO Offset Publication No.* 62, Geneva.