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ORIGINAL ARTICLE

K. Bester

Effects of pesticides on seagrass beds

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Abstract In the German Wadden Sea there has been a remarkable decline in seagrass beds. It was the aim of this study to test whether herbicide contamination could be a reason for this. Concentrations of triazine herbicides such as atrazine, simazine and terbutylazine as well as phenylurea herbicides were measured in Wadden Sea sediments within or in the neighbourhood of seagrass meadows. Sediments were thus used as a marker for medium-term contamination of the Wadden Sea. The respective concentrations were examined in relation to the density and status of the seagrass meadows. Preliminary results show that there may be a connection between seagrass decline and herbicide contamination in the parts of the Wadden Sea sampled. A comparison with other contamination is also given.

Key words Wadden Sea · Seagrass beds · Herbicides · *Zostera noltii* · Sediments

Introduction

Several millions of tons of pesticides are applied to fields annually world-wide (Bucheli et al. 1997; Müller et al. 1997) while about 30,000 t is used in each Germany and the Netherlands (Statistisches Bundesamt 1990; de Jong et al. 1995). Among these, herbicides are the most prominent followed by fungicides, while insecticides are less likely to be used in central and northern Europe, due to climatic conditions. It is estimated that about 1% of the pesticides applied reach the sea via rivers and the atmosphere (Bester 1996; Müller et al. 1997).

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K. Bester (✉)
Institut für Organische Chemie, Martin-Luther-King-Platz 6, 20146 Hamburg, Germany

Present address:
K. Bester, IRMM, Retieseweg, 2440 Geel, Belgium,
e-mail: kai.bester@irmm.jrc.be,
Tel.: +32-14-571706, Fax: +32-14-590406

About 600–800 t of pesticides thus reach the Wadden Sea annually. Some of these pesticides may have an effect on the marine ecosystems as has been shown in the case of atrazine affecting phytoplankton (Bester et al. 1995).

Modern pesticides have different characteristics from the traditional ones such as like DDT and HCH. They have a low pK_{ow} (2–4) and thus show little tendency to bioaccumulation. They are comparatively hydrophilic and polar and bind to sediment, which can be clay as well as organic material, via hydrogen bonds. Herbicides like the triazine pesticides (see Fig. 1) inhibit photosystem II, and by this mechanism they are able to have effects on all plants such as phytoplankton or possibly seagrass (*Zostera noltii*). These compounds can also be transformed to carcinogenic *N*-nitroso-derivatives. Little is known about the effects of the respective metabolites that have also been detected in the environment. In a political context it is interesting to note that though some derivatives (e.g. simazine and atrazine) are banned in Germany, there are dozens of derivatives of triazines and phenylureas (see Fig. 2) that are legally used in the EU.

As the seagrasses have been diminished in the past (since 1970; see Kastler and Michaelis 1999) several reasons for this change have been discussed. While in some

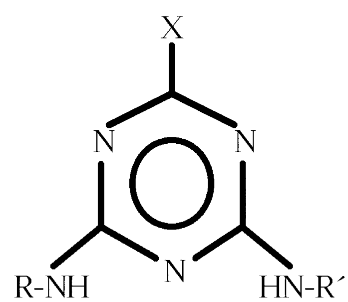

Fig. 1 Triazines: inhibit photosystem II; may have adverse effects on phytoplankton and algae; are hydrophilic (log K_{ow} = 1.5–4); are carcinogenic. Examples: simazine, atrazine, propazine, terbutylazine, prometryn, terbutryn, irgarol 1054. *R, R′* = alkyl-groups, *X* = Cl, MeO, MeS

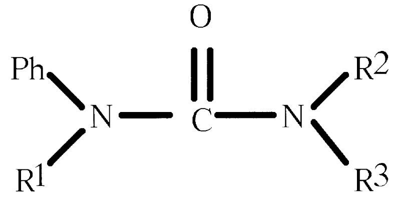

Fig. 2 Phenylurea herbicides: inhibit photosystem II; may have adverse effects on phytoplankton and algae; are hydrophilic (log K_{ow} = 1.5–4); possible carcinogenic metabolites. Examples: linuron, isoproturon, chloreturon, diuron. *Ph* = phenylgroup, *R1–3* = organic substituents

areas, including the Dutch Wadden Sea, restructuring of the coast was probably involved, for other areas heavy metal contamination were discussed (Warnau et al. 1995). Neither of these reasons apply in the area of the German Wadden Sea, as no such a restructuring has taken place and heavy metal contamination has decreased. On the other hand there were new results on pesticide inputs to the German Bight in 1991 (Bester and Hühnerfuss 1993). Also there were results from the Chesapeake Bay area showing that seagrass may be influenced by herbicides (Correll and Wu 1982).

Methods

For a preliminary study, several fields with seagrass communities in different condition were sampled on the East Friesian coast. It was considered to be feasible to sample the sediment as the water is changing too rapidly to give a reasonable reading for monitoring herbicide concentrations in the Wadden Sea. It was tested whether it was possible to measure herbicide contaminations at relevant concentrations and whether there was a possible correlation between damage to the seagrass and concentrations in the sediment.

Details of the method development are published elsewhere (Bester and Hühnerfuss 1996, 1997); generally speaking the samples were extracted with acetone, the condensed extracts were cleaned up with successive solid phase extraction (RP18) and size exclusion chromatography (Polygel column; see Bester and Hühnerfuss 1996, 1997). The classification of the seagrass populations was done by comparisons seen from mapping seagrass populations (Kastler and Michaelis 1999). The possible effects of the pesticides on seagrass populations are also discussed in this article.

Results

In Fig. 3, sampling stations from the experiment in 1993 are shown with the concentrations of the most prominent herbicides. Also shown is a rough classification of the status of the respective seagrass community as healthy (H), sparse/diminished (S) or dead/destroyed (D). It can be seen that the concentrations in the river Weser estuary are comparatively high (up to several thousand ng/kg for total pesticides or even for a single compound), while at other stations the concentrations were significantly lower (in hundreds of ng/kg). The pattern of the contamination is changing, as well as the amount (concentration) of

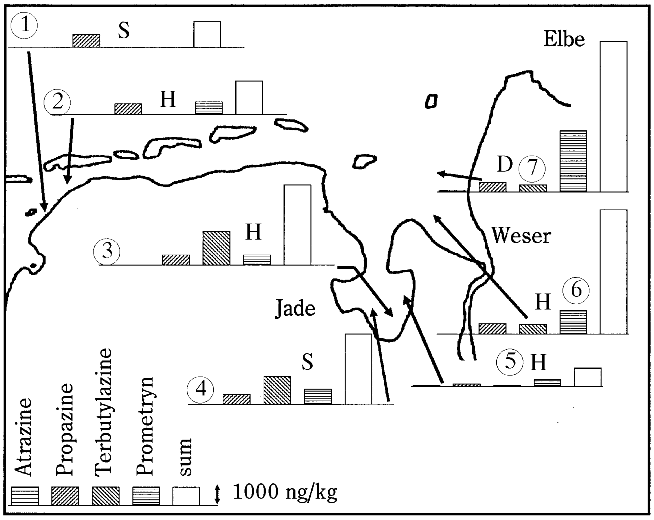

Fig. 3 Distribution of four triazine herbicides (atrazine, propazine, terbutylazine and prometryn) as well as the sum of the concentrations of the herbicides and metabolites, respectively (atraton, simazine, atrazine, propazine, terbutylazine, prometryn, terbutryn, desethylatrazine, desethyterbutylazine and linuron) in Wadden Sea sediment samples obtained in summer 1993. The concentrations are given in ng/kg wet weight. The respective numbers indicate the sampling site [*1*: W-Norddeich, *2*: Hilgenriedersiel (O-Norddeich), *3*: Sehestedt, *4*: Dangast (SW-Jade), *5*: Augustgroden (O-Jade), *6*: Langlütjensand, *7*: Eversand]. The state of the seagrass population is indicated by: *H,* healthy; *S,* sparse/diminished; *D,* total decline/destroyed

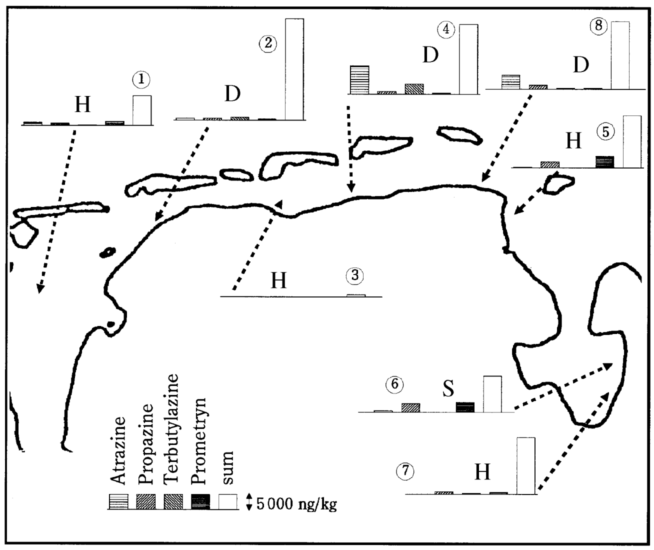

Fig. 4 Distribution of four triazine herbicides (atrazine, propazine, terbutylazine and prometryn) as well as the sum of the concentrations of the herbicides and metabolites, respectively (atraton, simazine, atrazine, propazine, terbutylazine, prometryn, terbutryn, desethylatrazine, desethyterbutylazine and linuron) in Wadden Sea sediment samples obtained in summer 1994. The concentrations are given in ng/kg wet weight. The respective numbers indicate the sampling site (*1*: Randzel; *2*: Hilgenriedersiel; *3*: Bensersiel; *4*: Neuharlingersiel; *5*: Horumersiel; *6*: Augustgroden; *7*: Sehestedt; *8*: Minsen). The state of the seagrass population is indicated by: *H,* healthy; *S,* sparse/diminished; *D,* total decline/destroyed

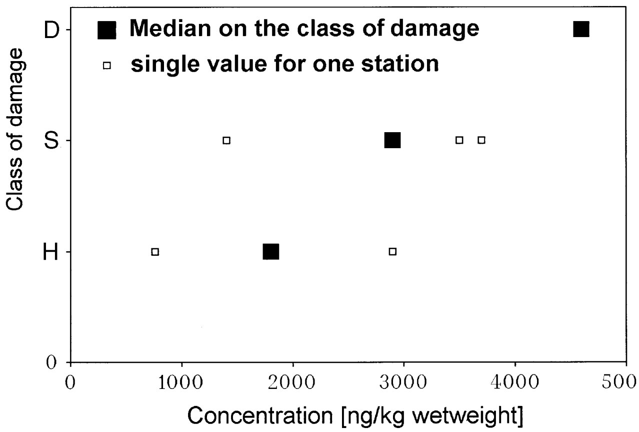

Fig. 5 Comparison of effects on seagrass with regard to the sum of the concentrations of relevant herbicides. Classes of damage are defined as destroyed (*D*), sparse/diminished (*S*) or healthy (*H*). Samples from 1993

pesticides. Propazine is more dominant at the western stations, while prometryn concentrations are higher at the eastern stations.

In Fig. 4, the results of the sampling in 1994 are displayed. This figure is not drawn to the same scale as Fig. 3. Other sampling stations were chosen in order to get a better overall impression of the situation. Generally, sampling was performed in a situation where destroyed and healthy seagrass beds were in close proximity in that year. At several stations the concentrations of the respective herbicides were higher in the destroyed seagrass beds. The values were generally higher in 1994 than in 1993. This may be attributed to the difference in sampling strategy as well as to real temporal changes.

To test for correlations between pesticide concentrations and effects on the seagrass populations, a plot (Fig. 5) was drawn. Considering the difference in pesticide patterns, the sum of the concentrations of herbicides was used rather than single concentrations under the assumption of additive toxicity. A tendency for a correlation of damage to high concentrations is visible. However, this trend obviously needs more data to confirme a hypothesis of actual damage.

Discussion

High concentrations of pesticides were found at places were seagrass communities had been destroyed. A correlative trend seems to be probable, though the statistics need to be strengthened by more experimental results. The concentration measured in the sediment will not be directly connected to the toxic effect, as the interaction of the plants with the contaminated water is probably higher than the interaction with the sediment. So the pesticides possibly enter the plants via the water as well as via the sediment. The situation is even more complex as the ecosystem is not only stressed by pesticides but by other xenobiotics as well. All of them show different toxicological properties, so it will be difficult to identify the final reason for the decline of seagrass if, indeed, xenobiotics are the controlling factor in this process. In Table 1 the presence and the effects of selected xenobiotics which are relevant in the Wadden Sea or the German Bight are shown. It is obvious that many different compounds (e.g. triazines, phenylureas, acetanilides, chlorophenols and chlorophenoxycarbonic acids, PAH, benzothiazoles, polycyclic musk fragrances, chloroanilines and chloronitroaromates) are present. Therefore, a large number of different toxic effects can be expected. Whether or not these effects are additive, and whether synergisms or antagonisms have to be taken into account, is not clear from the current state of knowledge and will need to be studied in the future. For those studies it is reasonable to use more controlled conditions, e.g. mesocosm experiments, to study dose-dependent

Table 1 Seagrass beds (like all organisms in the North Sea) are subject to a multi-compound attack

Compound	Effect	Presence	Reference
Triazines	e.g. Photosynthesis	North Sea and Wadden Sea	
Phenylureas	e.g. Photosynthesis	Wadden Sea	Meerendonk et al. (1994)
Acetanilides	e.g. Photosynthesis	Wadden Sea	Meerendonk et al. (1994)
Glyphosate/gluphosinate	e.g. Amino acid synthesis	Probably the most commonly used pesticide in Germany and the Netherlands	
Chlorophenols/chlorophenoxycarbonic acids	e.g. Growth stimulant	German Bight and North Sea	Hühnerfuss et al. (1990) Bundesamt für Seeschiffahrt und Hydrographie (1993) House et al. (1997)
PAH	e.g. DNA-adducts/cancer	Wadden Sea	de Jong et al. (1993)
Benzothiazoles	e.g. Toxic to microorganisms	German Bight	
Polycyclic musk fragrances	e.g. Bioaccumulation	German Bight	
Chlorinated anilines	e.g. Mutagenesis	German Bight	
Nitro-aromatic compounds	e.g. Mutagenesis	German Bight	
HCH (lindane)	Unknown/Neuro toxic	German Bight and Wadden Sea	

toxicology. It should be noted that most of the compounds mentioned in this study do not belong to those which are often summarised as persistent organic pollutants (POPs). In any case, they are persistent and they tend to have effects in the ecosystem.

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