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Degradation of Organchlorine Pesticides in Carbonate Sediments from the Aqaba Gulf, Red Sea

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Abstract: In order to show the role of sediment in buffering pesticide contamination in seawater, degradation of DDT, Antar and Herphosate in carbonate sediments were investigated. Degradation rates of organochlorine pesticides were calculated from oxygen consumption rate and ammonium production rate that were estimated by incubation of natural carbonate chambers with pesticides. The degradation rates of Antar under oxic and anoxic conditions were 90.7 ± 9.9 and 110.2 ± 17.0 mgC/m²/day¹, respectively, which were twofold higher than the rates of Herphosate under both conditions. Degradation of DDT in the sediment was almost zero indicating its higher stability. Statistical analysis shows no significant differences between the degradation under oxic and anoxic conditions. The highly permeable carbonate sediments which are composed mainly of unconsolidated fragments may play an important role in the mineralization of pesticides in marine environments.

Key words: Degradation, organochlorine pesticides, carbonate sediments, Red Sea, Aqaba Gulf

INTRODUCTION

A pesticide is defined as any substance or mixture of substances intended for preventing, destroying or controlling any pest; or substances which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies (FAO, 2005). Classification of pesticides is broadly based on their structure, where the dominant types being organochlorines, organophosphates, pyrethroids and carbamates (Briggs and Council, 1992). Although, pesticides are useful in improving crop yields and in limiting the spread of certain diseases, they have harmful effects; they can cause injury to human health as well as to the environment. They may also be non-biodegradable, persist in the environment and then accumulate in living organisms (Mansour, 2004). The chlorinated pesticides are mostly found in the environment because they were extensively used for at least two decades worldwide (1950-1970). Their stable structure, lipophilic nature and hydrophobicity account their accumulation in sediment and biological tissues (Swackhamer and Hites, 1988; Vassilopoulou and Gregoriades, 1993; Kang *et al.*, 2000; Wiberg and Harris, 2002; Galanopoulou *et al.*, 2005).

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Degradation of organic matter may occur aerobically or anaerobically, depending on the oxidizing agent. In aerobic degradation, oxygen is used as energy source. However, when dissolved oxygen becomes almost depleted, other anaerobic processes may occur, which utilize nitrate, manganese oxide, iron oxides, sulphate, carbon dioxide and methane as an energy source (Froelich *et al.*, 1979; Canfield, 1993). In some cases, aerobic degradation does not occur without a prior anaerobic process (Master *et al.*, 2002; Zhang and Bennett, 2005). Anaerobes use natural organics such as proteins, carbohydrates and many others as carbon and energy sources (Zhang and Bennett, 2005). In aerobic sediment, oxic respiration supply nitrate and nitrite for the water column (Hammond *et al.*, 1984; Berelsn *et al.*, 1998). In anaerobic sediment, ammonium can be supplied from nitrate reduction (Libes, 1992). Hence, the production rate of inorganic nutrients from the sediment can be used as an estimate of organic matter degradation (Rasheed *et al.*, 2003, 2006).

In the Jordanian site of the Gulf of Aqaba, Alawi *et al.* (1995) found contamination of the sediments with low concentrations of Heptachlor and hexachlorobenzene; however no organochlorine pesticide was found. A recent study was conducted that investigated in addition to hexachlorobenzene (HCB), three groups of organochlorine pesticides namely; DDT and its metabolites, hexachlorocyclohexane (α and β isomers) and cyclopentadiene group (Aldrin and Heptachlor) in water and sediments samples from the Gulf of Aqaba (Alawi *et al.*, 2007). The concentrations of the investigated pesticides were generally low with an average of 0.55, 3.77 and 4.91 $\mu\text{g kg}^{-1}$ in seawater, shore sand and sediment, respectively.

Carbonate sands are those that contain more than 50% biogenic carbonate, which cover approximately 10% of the continental shelves and are usually found in tropical and subtropical environments within coral reef ecosystems, as are those of the Gulf of Aqaba. Due to their chemical and physical properties, these sands play an important role in the degradation of Organic Matter (OM) (Alongi *et al.*, 1996; Rasheed *et al.*, 2002; Wild *et al.*, 2005, 2009; Rusch *et al.*, 2009). In the Gulf of Aqaba, Rasheed *et al.* (2003, 2006), studied the degradation rates of organic matter in reef sediments through O_2 consumption and ammonium production rates. The authors found high OM degradation rates in carbonate reef sediments compared with the rates in other sediments.

Although a wealth of information about biodegradation of pesticides is available, our current understanding of their biochemistry remains opaque among a variety of pesticides and detailed biochemical degradation pathways are still unknown for many pesticides, even for those in common use. Nevertheless, the types of biochemical reactions are limited and few (Alexander, 1981; Zhang and Bennett, 2005).

In this study, the degradations of some pesticides in reef carbonate sediments from the Gulf of Aqaba were estimated in order to show the role of sediment in buffering any contamination of organic particulate that may occur in the seawater.

MATERIAL AND METHODS

This study took place in the Marine Science Station (29°27'30.52"N, 34°58'34.03"E) at the Jordanian part of the Aqaba Gulf in the period of Oct., 2006 to Feb., 2008.

In order to estimate pesticide concentrations in water and sediments of the Gulf of Aqaba, samples were collected from the area belonging to the Marine Science Station (29° 27' 30.52" N, 34° 58' 34.03" E) on the Jordanian sector of the Gulf of Aqaba. Water samples were collected from the water surface. Sediment samples were collected from the shore sediment which was collected manually and from 5 m deep sediment which was

collected from the bottom by SCUBA diving using acrylic cylinders of 9.5 cm inner diameter and 40 cm length. Every sediment cylinder was divided into two equal parts; the surface sediments part and the deep sediment part. All sets of samples were air-dried at room temperature and sieved manually (pore diameter = 1 mm).

Pesticide Analysis

Organochlorine Pesticides were analyzed by GC (PERKIN ELMER, model Auto System XL) equipped with ⁶³Ni-ECD using the method described by Alawi *et al.* (2007). All primary standards of the organochlorine pesticides (98.2-99.9% pure) were purchased from SUPELCO (PA, USA). For qualitative and quantitative interpretation of results, a concentration of 1.0 ppm Aldrin was used as internal standard for the organochlorine pesticides mixture and the real sample final extract solutions.

The sonication method was used for sediment extraction using dichloromethane/n-hexane (1:1) mixture as a solvent, while water samples were extracted using dichloromethane as the Liquid-liquid extraction method. Florisil was used for the cleanup step. Each sample was weighed double and each extract was analyzed twice (Haynes and Johnson, 2000; Alawi *et al.*, 2007).

One liter of each water sample was extracted with 50 mL dichloromethane in a 2 L separatory funnel (Alawi *et al.*, 1995). The mixture was shaken manually for 5 min followed by collection of the lower organic layer. The extraction was repeated twice each time with 50 mL dichloromethane. The pooled 150 mL dichloromethane extracts were dried over anhydrous sodium sulfate and filtered. The solvent was evaporated to dryness under vacuum at = 40°C and 350 mbar. The residues were dissolved in 1 mL n-hexane containing 1 ppm Aldrin as internal standard.

To evaluate the whole analytical procedure, the percent recovery of each of the studied organochlorine pesticides under study was determined for each residue analytical procedure concerning each sample type. This was performed by spiking with a known concentration of the organochlorine pesticide mixture. The analysis of each sample was performed according to its specific analytical procedure. The recoveries were 92.8-99.5% for the sediment samples.

Degradation of Pesticides in Carbonate Sediments

Carbonate natural cores were collected from a coral reef site in the Marine Science Station (29°27'30.52"N, 34°58'34.03"E). The cores were collected using acrylic flux chambers with 9.5 cm inner diameter and 40 cm height. The cores were collected by SCUBA diver chambers were inserted to approximately 15 cm deep in the sediment. Upon return to the lab, small amounts (5 mL) of different pesticides were mixed with the carbonate sediments (within the top layer, above 5 cm). Some chambers were used as controls and remained without any added material (Table 1). The chambers were covered with gastight plastic lids with two sampling ports. To avoid stratification, the water above all sediments was stirred using a rotating disk placed above the sediment surface (Rasheed *et al.*, 2003).

Table 1: Summary of incubation experiments carried out in this study with the added pesticides

Pesticides	No. of chambers	Duration (h)
ANTAR	4 control	240
	4 spiked	
DDT	4 control	260
	4 spiked	
Herphosate	3 control	260
	4 spiked	

Water samples were collected from the water above the sediment to monitor the concentration of dissolved oxygen as well as the concentration of ammonium as a function of incubation time. Oxygen was determined using the Winkler method according to Grasshoff (1999). Ammonium concentrations were analysed by spectrophotometrically according to Grasshoff (1999).

Rates Calculation

Degradation rates of pesticides were calculated from oxygen consumption rate and ammonium production rate which were evaluated using the linear regressions of oxygen and ammonium concentrations over time after subtraction of the rates recorded in the control chambers. Degradation under oxic condition was calculated using a ratio of 1 for CO₂ (production): 1 for O₂ (consumption) as used by Berelsn *et al.* (1998), Rasheed *et al.* (2003) and Wild *et al.* (2005). Anoxic degradation was estimated using ammonium production rate assuming a Redfield ration of C:N ratio of 106:16. Oxic degradation was estimated from the initial oxygen consumption rate when oxygen concentration in the water was still higher than 10% oxygen air saturation. Anoxic degradation was estimated from ammonium production rate when oxygen concentration in the water was almost stable; i.e., when mostly less than 10% oxygen air saturation.

RESULTS AND DISCUSSION

Concentrations of Pesticides in the Water and Sediment

Organochlorine pesticides were measured in water and sediments of the Marine Science Station (Table 2). Organochlorine pesticide concentrations were very low in seawater compared to their concentration in sediments; this is expected considering their lipophilic properties (Alawi *et al.*, 2007). p,p'-DDT and β-HCH showed higher concentrations compared to other pesticides and were detected in all seawater and sediment samples. This could be attributed to their high persistency, high stability and their historical use in Jordan (Alawi *et al.*, 1995, 2007).

The lower part of the sediment showed generally low concentrations compared to the upper part except for β-HCH. This could be attributed to environmental contamination in the past, which was lower than in recent times. The possible higher degradation rate of some pesticides in anaerobic conditions in deep sediments as has been improved in this study in addition to the higher time available for different degradation processes in the case of the deep sediments.

Table 2: Organochlorine pesticide concentrations (µg kg⁻¹) in the marine science station area as an average of two different samples and two runs for each sample

Organochlorine pesticide	Water	Shore-sediment	5 m sediment	5 m LP
α-HCH	<d.l.	0.018	0.010	0.005
HCB	<d.l.	0.009	0.051	0.005
Heptachlor	0.001	0.109	0.037	0.013
Aldrin	<d.l.	<d.l.	<d.l.	<d.l.
o,p'-DDE	<d.l.	0.049	0.047	<d.l.
p,p'-DDE	<d.l.	0.286	0.028	<d.l.
o,p'-DDD	<d.l.	<d.l.	<d.l.	0.050
p,p'-DDD	<d.l.	<d.l.	<d.l.	<d.l.
o,p'-DDT	<d.l.	<d.l.	<d.l.	<d.l.
p,p'-DDT	0.539	1.964	0.523	0.222
β-HCH	0.201	3.821	0.055	0.130

Up: Upper part of the collected core; LP: Lower part of the collected core; <d.l.: Below detection limit

The comparison of the organochlorine pesticides levels in seawater obtained in the present work with the values reported by other workers (Table 3), shows that the concentrations are within reported concentrations for the Gulf of Aqaba (Alawi *et al.*, 1995, 2007). However, they are mostly lower than those found for London Harbor (Fatoki and Awofolu, 2003). This can be attributed to the lack of agriculture, or grazing activities in Aqaba. The levels in the sediments are within the range of or lower than the concentrations in coastal sediments of the Gulf of Aqaba, in Harbor sediments from London and in coral sediments from Red Sea (Table 4), except for o,p'-DDE, p,p'-DDE and β -HCH, where their concentrations are higher than the other findings. This might be explained by their high persistency, high stability and their use in Jordan for long time (Alawi *et al.*, 1995) as o,p'-DDE and p,p'-DDE are the DDT metabolites .

Degradation Experiments

Antar

In the control chambers, dissolved oxygen (DO) concentration decreased immediately with a relative high rate of about $1.7 \mu\text{M h}^{-1}$ in the first 72 h, reaching almost $100 \mu\text{M}$ (Fig. 1a-d) and then decreasing slightly to a lower rate ($0.08 \mu\text{M h}^{-1}$). Ammonium, however, increased gradually with a rate of $0.36 \mu\text{M h}^{-1}$ in the first 200 h and then increased only slightly to the end of the incubation period. In the chambers with spiked Antar, DO concentrations dropped with a high rate ($4.33 \mu\text{M h}^{-1}$) to reach a value of about $20 \mu\text{M}$ after 48 h which indicated a high degradation rate of Antar in the sediment. Ammonium concentrations in the same chambers started to increase gradually in the first 48 h, reaching

Table 3: Organochlorine pesticide concentrations ($\mu\text{g kg}^{-1}$) in the seawater for this study and other studies

Organochlorine pesticide	Water Gulf of Aqaba Alawi <i>et al.</i> (1995)	Water Gulf of Aqaba Alawi <i>et al.</i> (2007)	Water London harbor Fatoki and Awofolu (2002)	Present study
a-HCH	0.052	0.001	NA	<d.l.
HCB	0.004	0.002	0.04	<d.l.
Heptachlor	0.022	0.002	0.08	0.001
Aldrin	<d.l.	<d.l.	0.08	<d.l.
o,p'-DDE	0.028	0.004	0.008	<d.l.
p,p'-DDE	0.176	0.002	NA	<d.l.
o,p'-DDD	<d.l.	<d.l.	0.006	<d.l.
p,p'-DDD	0.038	0.003	0.013	<d.l.
o,p'-DDT	<d.l.	0.003	0.006	<d.l.
p,p'-DDT	0.063	0.392	0.019	0.539
β -HCH	0.042	0.133	NA	0.201

NA: Not available, <d.l.: Below detection limit

Table 4: Organochlorine pesticide concentrations ($\mu\text{g kg}^{-1}$) in the sediment for this study and other studies

Organochlorine pesticide	Sediment Gulf of Aqaba Alawi <i>et al.</i> (1995)	Sediment Gulf of Aqaba Alawi <i>et al.</i> (2007)	Corals Red Sea El Nemr <i>et al.</i> (2004)	Sediment London Harbor Fatoki and Awofolu (2003)	Present study
a-HCH	0.9	<d.l.	0.014	NA	0.018
HCB	NA	0.068	0.008	0.0019	0.009
Heptachlor	0.3	0.380	0.083	0.0012	0.109
Aldrin	0.6	<d.l.	<d.l.	0.0008	<d.l.
o,p'-DDE	NA	<d.l.	0.003	0.0008	0.049
p,p'-DDE	4.1	<d.l.	0.134	NA	0.286
o,p'-DDD	NA	<d.l.	0.119	0.0006	<d.l.
p,p'-DDD	1.2	<d.l.	0.035	0.0013	<d.l.
o,p'-DDT	NA	<d.l.	<d.l.	0.0006	<d.l.
p,p'-DDT	0.4	<d.l.	0.559	0.0019	1.964
β -HCH	1.4	0.064	2.771	NA	3.821

NA: Not available, <d.l.: Below detection limit

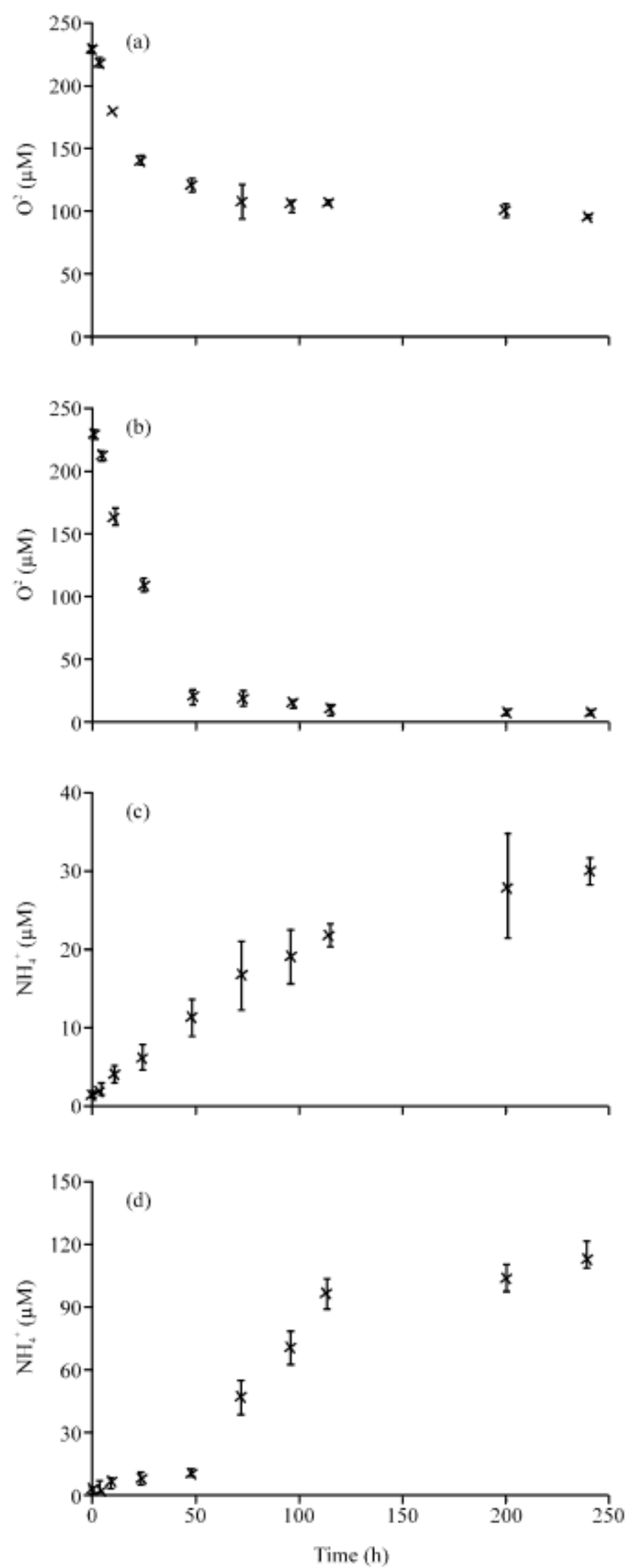


Fig. 1: Time course of dissolved oxygen and ammonium concentrations (μM) during the incubation of control and spiked-Antar sediments. Error bars represent the standard deviation of the concentrations from different chambers. (a) Oxygen control, (b) oxygen antar, (c) ammonium control and (d) ammonium antar

a value of 10 μM and then increased sharply to about 100 μM at 114 h. There was only a further slight increase till the end of the incubation period. Notably here that ammonium started to increase rapidly when oxygen level become very low after 48 h indicating high degradation rate of Antar under anoxic conditions.

Herphosate and DDT

In control chambers of both pesticides (figure not shown), the time course of DO and ammonium production and consumption, respectively, were almost the same as for Antar. As for spiked-Herphosate sediments, oxygen decreased with a rate of 2.7 $\mu\text{M h}^{-1}$ in the first 72 h to reach a concentration of 20 μM , then remained almost stable to the end of the incubation period (Fig. 2a-d). Ammonium increased gradually during the first 50 h and then increased sharply with a rate of 0.26 $\mu\text{M h}^{-1}$. Obviously, DO and ammonium in DDT spiked sediments followed the same trend as in control sediments without spiking (Fig. 1, 2), thus indicating a low degradation rate for DDT.

Degradation Rates of Different Pesticides in Carbonate Sediments

Figure 1 and 2 show oxic degradation of Antar was calculated using oxygen consumption rate for the first 48 h, while anoxic degradation was calculated from ammonium production rate in the period after that (between 48-240 h) when oxygen saturation was less than 10%. Herphosate degradation under oxic concentration was calculated from oxygen consumption in the first 72 h and from ammonium production after that time to the end of the incubation period. As for DDT, however, the degradation rate was calculated only under oxic condition as anoxia was never reached during the incubation time (Fig. 2).

The degradation rates of Antar were much higher than the degradation rates of DDT and about two fold higher than those of Herphosate in oxic and anoxic conditions (Table 5). The DDT degradation in the sediment was almost zero, indicating higher stability of this pesticide. Although the degradation of DDT to DDE in the coastal sediments is well documented (Sarkar and Sen Gupta, 1988), the degradation of DDT was found to be slow in marine environments (Tavares *et al.*, 1999; Yuan *et al.*, 2001). The differences in degradation rates among different pesticides may be attributed to the chemical property and structure of each pesticide considering organic matter type is one important factor that affects degradation in sediments (Boudreau, 2000; Aller, 2004; Rasheed *et al.*, 2004).

Oxic degradation rates of Antar and Herphosate were comparable with those of anoxic degradation. Statistical analysis (ANOVA analysis, at 10% significance level) shows no significant differences between the two degradation pathways ($p > 0.1$) which is in agreement with other authors who demonstrated that organic matter degradation rates are usually not significantly different (Lee, 1992; Westrich and Berner, 1984). Studies on the biodegradation of pesticides appear to be focused mostly on aerobic bacteria, despite some limited studies were based on the isolation of anoxic bacterial cultures (Ruppe *et al.*, 2003, 2004). DDT was found to have high resistance to degradation in oxic sediment environment (Fig. 2). Zhang and Bennett (2005) found slow anaerobic degradation processes for persistent organic compounds, including polychlorinated biphenyls, dioxins and DDT. Natural degradation can therefore only occur on a long-term basis. Under such anaerobic conditions, the enzymatic reactions common to many pesticides include dechlorination, hydrolysis, nitro reduction and dealkylation (Williams, 1977). While lightly halogenated pesticides are more biodegradable under aerobic conditions, it is commonly believed that highly halogenated pesticides often biodegrade more rapidly under anaerobic conditions (Zhang and Bennett, 2005). The degradation of the pesticide atrazine has been reported to occur mainly under anoxic conditions (Ghosh and Philip, 2004; Kao *et al.*, 2001; Seybold *et al.*, 2001).

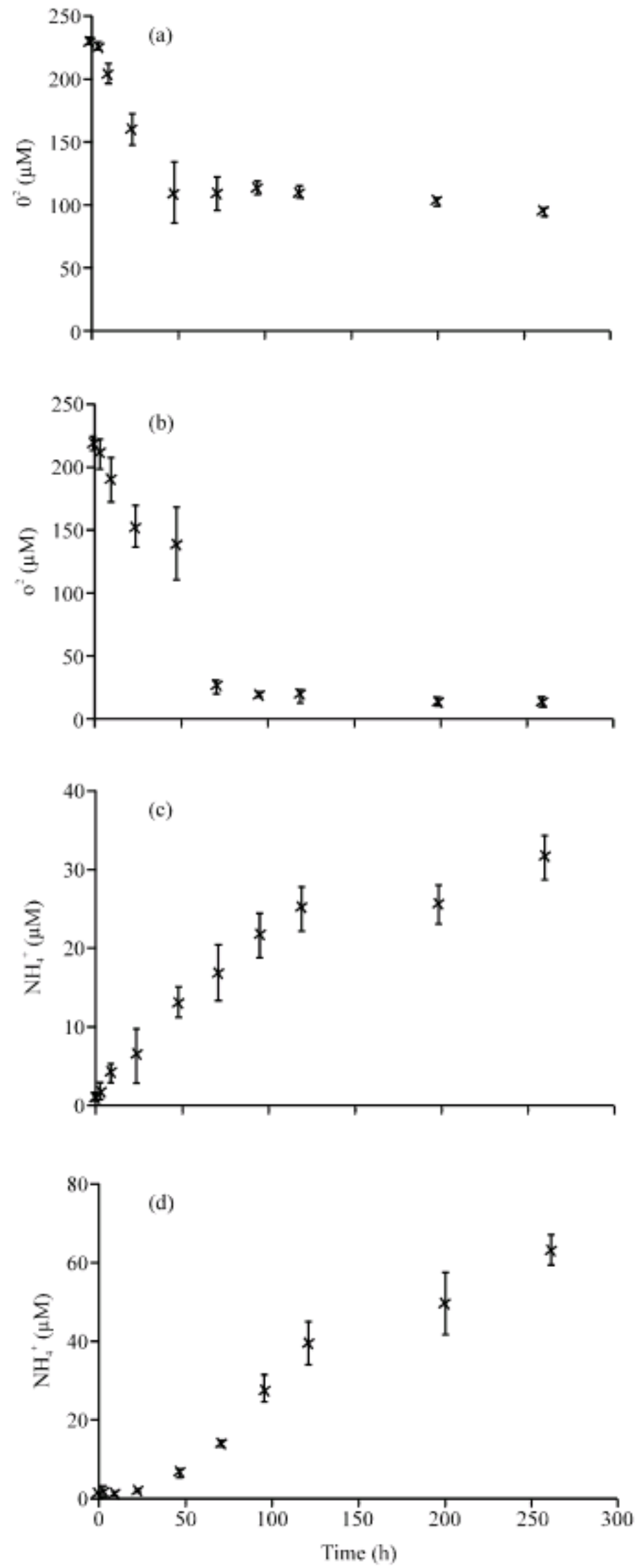


Fig. 2: Time course of dissolved oxygen and ammonium concentrations (μM) during the incubation of spiked DDT and Herphosate with sediments. Error bars represent the standard deviation of the average concentrations from different chambers. (a) Oxygen DDT, (b) oxygen herphosate, (c) ammonium DDT and (d) ammonium herphosate

Table 5: Average degradation rates and standard deviations of pesticides (mgC/m²/day¹) under oxic and anoxic condition inferred from oxygen production and ammonium production, respectively

Factors	Oxic	Anoxic
Antar	90.70±9.9	110.20±17.0
Herphosate	40.54±15.0	053.21±04.3
DDT	00.35±0.56	*

*No anoxic degradation was calculated factor DDT because oxygen concentrations were always above 10% saturation

Carbonate sediments which are composed mainly of unconsolidated fragments play an important role in the degradation of organic matter. The high porosity and permeability of these sediments allow water currents to penetrate and re-suspend these sands, which enhance advective transport through these sediments and therefore, enhance organic matter mineralization rate in sediments (Tribble *et al.*, 1992; Riegl, 1995; Rasheed *et al.*, 2003, 2004, 2006; Rusch *et al.*, 2006; Wild *et al.*, 2009). According to Rusch *et al.* (2006), the decomposition rates of organic matter in permeable sands can exceed those of fine-grained, organic rich deposits as a result of advective flow. The upper layers of the coral sands are well aerated and illuminated and are inhabited by dense population of micro-algae, bacteria and microzoobenthos (Sorkin, 1995). Such microbial communities inhabiting permeable sediments are important in organic matter degradation and nutrient cycling in coral reef ecosystems (Rasheed *et al.*, 2002; Wild *et al.*, 2005; Rusch *et al.*, 2009). Thus, carbonate sands that are found in tropical and subtropical areas can be suitable substrate to reduce any contaminations from some pesticides which can be inserted into the sea through anthropogenic activities.

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REFERENCES

- Alawi, M.A., M. Hourani and D. Abu Hilal, 1995. Levels of organochlorine pesticides in fish, algae sediments and seawater samples in the Aqaba gulf. *Toxicol. Environ. Chem.*, 51: 121-134.
- Alawi, M., M. Rasheed and M.G. Al-Masri, 2007. Organochlorine pesticides in seawater and sediment samples from the Aqaba gulf. *Fresenius Environ. Bull.*, 16: 1131-1136.
- Alexander, M., 1981. Biodegradation of chemicals of environmental concern. *Science*, 211: 132-138.
- Aller, R.C., 2004. Conceptual models of early diagenetic processes: the muddy seafloor as an unsteady batch reactor. *J. Marine Res.*, 62: 815-835.
- Alongi, D.M., F. Tirendi and A. Goldrick, 1996. Organic matter oxidation and sediment chemistry in mixed terrigenous-carbonate sands of Ningaloo Reef Western Australia. *Mar. Chem.*, 54: 203-219.
- Berelsn, W.M., D. Heggie, A. Longmore, T. Kilgore, G. Nicholson and G. Skyring, 1998. Benthic nutrient recycling in Port Phillip Bay Australia. *Est. Coast. Shelf Sci.*, 46: 917-934.

- Boudreau, B.P., 2000. The mathematics of early diagenesis from worms to waves. *Rev. Geophys.*, 38: 389-416.
- Briggs, S.A. and R.C. Council, 1992. *Basic Guide to Pesticides: Their Characteristics and Hazards*. 5th Edn., Hemisphere Publishing Corporation, Washington, DC., ISBN: 1-56032-253-5.
- Canfield, D.E., 1993. Organic Matter Oxidation in Marine Sediments. In: *Interactions of C, N, P and S Biogeochemical Cycles and Global Change*, Wollast, R., F.T. Mackenzie and L. Chou (Eds.). NATO ASI Series, Springer, New York, pp: 333-363.
- El-Nemr, A., A. El-Sikaily, A. Khaled, T.O. Said and A.M.A. Abd-Allah, 2004. Chlorinated pesticides and polychlorinated biphenyls in the coral reef skeleton of the Egyptian Red Sea Coast. *Bull. Environ. Contam. Toxicol.*, 72: 1195-1202.
- Fatoki, O.S and R.O. Awofolu, 2003. Methods for selective determination of persistent organochlorine pesticide residues in water and sediments by capillary gas chromatography and electron-capture detection. *J. Chromatogr. A*, 983: 225-236.
- FAO., 2005. *International Code of Conduct on the Distribution and use of Pesticides Revised Version*. Food and Agriculture Organization, Rome.
- Froelich, P.N., G.P. Klinkhammer, M.L. Bender, N.A. Luedtke and G.R. Heath *et al.*, 1979. Early oxidation of organic matter in pelagic sediments of the eastern equatorial Atlantic suboxic diagenesis. *Geochim et Cosmochim Acta*, 43: 1075-1090.
- Galanopoulou, S., A. Vgenopoulos and N. Conispoliatis, 2005. DDTs and other chlorinated organic pesticides and polychlorinated biphenyls pollution in the surface sediments of Keratsini harbour Saronikos gulf Greece. *Marine Pollut. Bull.*, 50: 520-525.
- Ghosh, P.K. and L. Philip, 2004. Atrazine degradation in anaerobic environment by a mixed microbial consortium. *Water Res.*, 38: 2276-2284.
- Grasshoff, M., 1999. The shallow water gorgonians of New-Caledonia and adjacent islands (Coelentera: Octocorallia). *Frankfurt am Main Senckenbergiana Biol.*, 78: 1-245.
- Hammond, D.E., P. Giordani, G. Montanari, A. Rinaldi and R. Poletti *et al.*, 1984. Benthic flux measurements in NW Adriatic coastal waters. *Memoirs Soc. Geol. Italy*, 27: 461-467.
- Haynes, D. and J.E. Johnson, 2000. Organochlorine heavy metal and polycyclic aromatic hydrocarbon pollutant concentrations in the great barrier reef (Australia) environment a review. *Marine Pollut. Bull.*, 41: 267-278.
- Kang, Y., G. Sheng, J. Fu, B. Mai, G. Zhang, Z. Lin and Y. Min, 2000. Polychlorinated biphenyls in surface sediments from Pearl River Delta and Macau. *Marine Pollut. Bull.*, 40: 794-797.
- Kao, C.M., J.Y. Wang and M.J. Wu, 2001. Evaluation of atrazine removal processes in a wetland. *Water Sci. Technol.*, 44: 539-544.
- Lee, C., 1992. Controls on organic carbon preservation the use of stratified water bodies to compare intrinsic rates of decomposition in oxic and anoxic systems. *Geochim. Cosmochim. Acta*, 56: 3323-3335.
- Libes, S.M., 1992. *An Introduction to Marine Biogeochemistry*. 1st Edn., John Wiley and Sons, New York, ISBN: 9780471509462.
- Mansour, S.A., 2004. Pesticide exposure Egyptian scene. *Toxicology*, 198: 91-115.
- Master, E.R., V.W.M. Lai, B. Kuipers, W.R. Cullen and W.W. Mohn, 2002. Sequential anaerobic-aerobic treatment of soil contaminated with weathered Aroclor 1260. *Environ. Sci. Technol.*, 36: 100-103.
- Rasheed, M., M.I. Badran, C. Richter and M. Huettel, 2002. Effect of reef framework and bottom sediment on nutrient enrichment in a coral reef of the Gulf of Aqaba Red Sea. *Marine Ecol. Prog. Ser.*, 239: 277-285.

- Rasheed, M., M.I. Badran and M. Huettel, 2003. Influence of sediment permeability and mineral composition on organic matter degradation in three sediments from the Gulf of Aqaba, Red Sea. *Estuarine, Coastal Shelf Sci.*, 57: 369-384.
- Rasheed, M., C. Wild, U. Franke and M. Huettel, 2004. Benthic photosynthesis and oxygen consumption in permeable carbonate sediments at Heron Island Great Barrier Reef, Australia. *Estur. Coast. Shelf Sci.*, 59: 139-150.
- Rasheed, M., C. Wild, C. Jantzen and M. Badran, 2006. Mineralization of particulate organic matter derived from coral-reef organisms in reef sediments of the Gulf of Aqaba. *Chem. Ecol.*, 22: 13-20.
- Riegl, B., 1995. Effects of sand deposition on scleratinian and alcyonacean corals. *Mar. Biol.*, 121: 517-526.
- Ruppe, S., A. Neumann and W. Vetter, 2003. Anaerobic transformation of compounds of technical toxaphene. I. Regiospecific reaction of chlorobornanes with geminal chlorine atoms. *Environ. Toxicol. Chem.*, 22: 2614-2621.
- Ruppe, S., A. Neumann and W. Vetter, 2004. Anaerobic transformation of compounds of technical toxaphene. II. Fate of compounds lacking geminal chlorine atoms. *Environ. Toxicol. Chem.*, 23: 591-598.
- Rusch, A., M. Huettel, C. Wild and C. Reimers, 2006. Benthic oxygen consumption and organic matter turnover in organic-poor permeable shelf sands. *Aquatic Geochem.*, 12: 1-19.
- Rusch, A., A.K. Hannide and E. Gaidos, 2009. Diverse communities of active bacteria and archaea along oxygen gradients in coral reef sediments. *Coral Reefs*, 28: 15-26.
- Sarkar, A. and R. Sen Gupta, 1988. DDT residues in sediments from the Bay of Bengal. *Bull. Environ. Contam. Toxicol.*, 41: 664-669.
- Seybold, C.A., W. Mersie and C. McNamee, 2001. Anaerobic degradation of atrazine and metolachlor and metabolite formation in wetland soil and water microcosms. *J. Environ. Qual.*, 30: 1271-1277.
- Sorkin, Y.I., 1995. Coral Reef Ecology. In: *Ecological Studies*, Heldmaier, G., O.L. Lange, H.A. Mooney and U. Sommer (Eds.). Springer-Verlag, Berlin, pp: 464.
- Swackhamer, D.L. and R.A. Hites, 1988. Occurrence and bioaccumulation of organochlorine compounds in fishes from Siskewit Lake, Isle Royale, Lake Superior. *Environ. Sci. Technol.*, 22: 543-548.
- Tavares, T.M., M. Beretta and M.C. Costa, 1999. Ratio of DDT/DDE in the All Saints Bay Brazil and its use in environmental management. *Chemosphere*, 38: 1445-1452.
- Tribble, G.W., F.J. Sansone, R.W. Buddemeier and Y.H. Li, 1992. Hydraulic exchange between a coral reef and surface seawater. *Geol. Soc. Am. Bull.*, 104: 1280-1291.
- Vassilopoulou, V. and E.G. Gregoriades, 1993. Factors influencing the uptake of organochlorines in red mullet (*Mullus barbatus*) from a gulf of Central Greece. *Marine Pollut. Bull.*, 26: 285-287.
- Westrich, J.T. and R.A. Berner, 1984. The role of sedimentary organic-matter in bacterial sulfate reduction the G Model tested. *Limnol. Oceanography*, 29: 236-249.
- Wiberg, P.L. and C.K. Harris, 2002. Desorption of p,p'-DDE from sediment during resuspension events on the Palos Verdes shelf, California a modeling approach. *Continental Shelf Res.*, 22: 1005-1023.
- Wild, C., M. Rasheed, C. Jantzen, P. Cook, U. Struck, M. Huettel and A. Boetius, 2005. Ethnic metabolism and degradation of natural particulate organic matter in carbonate and silicate reef sands of the northern Red Sea. *Marine Ecol. Prog. Ser.*, 298: 69-78.

- Wild, C., M. Naumann, A. Haas, U. Struck, F. Mayer, M. Rasheed and M. Huettel, 2009. Coral sand O₂ uptake and pelagic-benthic coupling in a subtropical fringing reef, Aqaba, Red Sea. *Aquatic Biol.*, 6: 133-144.
- Williams, P.P., 1977. Metabolism of synthetic organic pesticides by anaerobic microorganisms. *Residue. Rev.*, 66: 63-135.
- Yuan, D., D. Yang, T.L. Wade and Y. Qian, 2001. States of persistent organic pollutants in the sediments from several estuaries in China. *Environ. Pollut.*, 114: 101-111.
- Zhang, C. and G.N. Bennett, 2005. Biodegradation of xenobiotics by anaerobic bacteria. *Appl. Microbiol. Biotechnol.*, 67: 600-618.