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Molluscan Biofacies and their Environmental Implications, Nile Delta Lagoons, Egypt

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ABSTRACT

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Molluscan assemblages and their distribution in surficial sediment of Idku, Burullus and Manzala lagoons and Mariut lake in the northern Nile delta, Egypt, are defined. Quantitative analysis is performed on thanatocoenoses comprising a total of 47 species using a principal component analysis to distinguish the molluscan biofacies. Cumulative dominance values of fresh-water, lagoon *sensu stricto* and marine settings, calculated for molluscan assemblages in each sample, reveal considerable faunal variability within and between the four Nile delta water bodies.

Three molluscan biofacies are identified: those recording a marine, a fresh-water and a lagon *sensu stricto* influence. Biofacies indicate that, of the three lagoons, Manzala has the most fresh-water affinity and also receives the greatest incursion of marine waters via its outlet. Mariut lake biofacies, comparable to those of the Nile lagoons, likely record its history early in the last century when it was a lagoon connected to the Mediterranean. As a result of relatively high freshwater input, modern Nile molluscan biofacies comprise larger proportions of fresh-water species than in many other Mediterranean lagoons. The smaller number of molluscan biofacies and their more extensive geographic distribution in modern Nile lagoons, as compared to petrological subfacies, are a function of sediment transport-related phenomena.

The results of this study are applied to the fossil record in short cores from former Abu Qir lagoon, as old as 200 years, and older Holocene sequences in the underlying northern delta. Molluscan biofacies in these older units indicate settings that are somewhat less fresh-water and more lagoon *sensu stricto* influenced than those in modern Nile lagoons. Since molluscan faunas are sensitive markers of environmental conditions, it is recommended that their distributions in baseline studies be monitored in Nile delta lagoons and Mariut lake which are undergoing drastic modification by man.

ADDITIONAL INDEX WORDS: *Fossil record, Holocene sequence, biomarker, lagoonal facies, deltaic facies, thanatocoenoses, molluscan assemblage.*

INTRODUCTION

This investigation defines molluscan assemblages and interprets their origin in modern and Holocene lagoon deposits in the northern Nile delta of Egypt. Special attention is paid herein to Mariut, Idku, Burullus and Manzala, the four brackish water bodies of variable size which cover a large area of the lower delta plain (Figure 1). Mariut, a lake, is enclosed and has been without a major connection to the sea since the nineteenth century (De Cosson, 1935). In contrast, the other three display typical lagoon characteristics (*cf.* Kerambrun, 1986; Kjerfve and Magill, 1989; Ward and Ashley, 1989): each is elongate, oriented generally parallel to the coast, shallow (< 2.5 m), separated from the Mediterranean Sea by low, long and narrow coastal sand barriers, and connected to the sea by an outlet. Vegetation-covered islets abound in all lagoon basins. Lagoons were previously fed by River Nile distributaries (Arrowsmith, 1807; Jacotin, 1818; Toussoun, 1922) and overbank flooding, but presently receive much of their fresh to slightly saline water from irrigation channels and drains that flow primarily from the south (Iwaco, 1989; Sestini, 1992).

A number of studies have called attention to the dark, organic- and plant-rich deposits that accumulate in these lagoons on the Nile delta plain (Shafei, 1946; Said, 1958; Butzer, 1959, 1976; UNDP/UNESCO, 1978). The most obvious attributes of these muds and sandy silts, sometimes interbedded with thin sand laminae, are their gray

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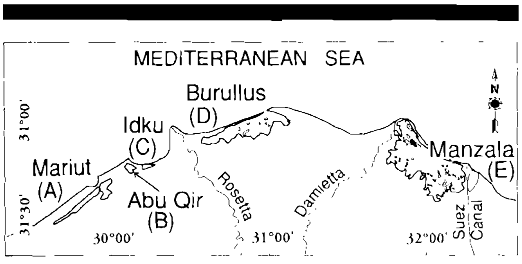

Figure 1. Map of northern Nile delta region of Egypt, showing Mariut lake (A), three modern lagoons [Idku (C); Burullus (D); Manzala (E)], and former Abu Qir lagoon (B). Details of the five regions and sample sites are shown in Figure 2.

to dark olive color, abundant shell and plant layers, and root and biogenic structures visually observed in split core sections and in x-radiographs. On the basis of these and associated petrologic and stratigraphic considerations, Coutellier and Stanley (1987) were able to readily distinguish Holocene lagoon from interfingering coastal and marine deltaic facies.

Both faunal and floral components are characteristic of Nile lagoon deposits but, to date, few comprehensive studies of these biogenic fractions have been made in either present-day or Holocene Nile delta sequences. Moreover, the various investigations which record shell-rich sediments on the floor of modern delta lagoons have not detailed the specific nature of the molluscan assemblages (El-Wakeel and Wahby, 1970; Saad, 1976a,b, 1978; Loizeau and Stanley, 1993). General lists of modern molluscan faunas for various regions of northeast Africa, including Egypt (Pallary, 1911; Steuer, 1939; Brown, 1980; Damme, 1984), are of value in this respect. With this as a base, a recent study was initiated to define modern molluscan assemblages in the three major lagoons and Mariut lake in the Nile delta (Longo, 1992).

Primary considerations here are to (1) define modern molluscan biofacies on the basis of statistical analysis of faunas identified by Longo (1992), and (2) determine their geographic distributions in the three Nile delta lagoons. The quantitative examination of faunal data was undertaken to refine interpretations on present environmental conditions affecting these shallow water bodies. This is of importance because all modern Nile lagoons are undergoing very rapid change (reduction in size, pollution) as a result of accelerated anthropogenic activity, and their demise is expected to have potentially serious repercussions for the delta region (Stanley and Warne, 1993).

In addition, the methodology developed for analysis of molluscan assemblages in Nile lagoons is applied herein to interpret those recorded in Mariut lake, the enclosed water body on the northwestern delta margin. Findings on modern molluscan assemblages are also applied to cores recovered in former Abu Qir lagoon (Figure 2B), drained more than a century ago as a result of land reclamation, and to older Holocene lagoon sequences in cores recovered in the lower Nile delta plain (Figure 2B).

METHODOLOGY

A total of 78 bulk samples were examined in the present study. Forty of these are from surficial samples (Figure 2A, C–E), collected with a 5-liter grab sampler during two field expeditions (1989, 1990): in Manzala (20 samples), Burullus (4 samples) and Idku lagoons (10 samples), and in Mariut lake (6 samples). All surficial samples were kept in 4% formaline solution to preserve the living fauna (biocoenosis). Also examined in this study are 13 bulk samples (~100 cm^3) from four short cores (to 70 cm depth) recovered in former Abu Qir lagoon during a 1992 survey (Figure 2B), and 25 coarse fraction (> 0.5 mm) residues from lagoon sections in 3 long cores (to 9 m depth) collected in the northwest Nile delta (Figure 2B).

Faunal components (mollusc, polychaete, crustacean and bryozoan remains) were separated from the terrigenous fraction using a 1 mm sieve in the case of surficial samples, and a 0.5 mm sieve for core samples. With respect to molluscan material separated from these surficial samples, the living molluscs (biocoenosis, usually in low proportions), were distinguished from the non-living fauna (thanatocoenosis). This study focuses on the thanatocoenoses because of their higher proportions in most samples. The species forming these thanatocoenoses are considered autochthonous, *i.e.*, they have not been substantially displaced after death. Mollusc shells attributed to the thanatocoenoses range in size from 0.5 mm to 4 cm.

Shells were identified, and the number of specimens in each taxon counted following the method proposed by Di Geronimo and Robba (1976). Abundance of taxa (A = number of specimens of a given taxon in a given sample), and dominance of taxa (D = abundance of taxon in a given sample divided by the total number of specimens of that sample) are recorded, respectively, in Tables 1

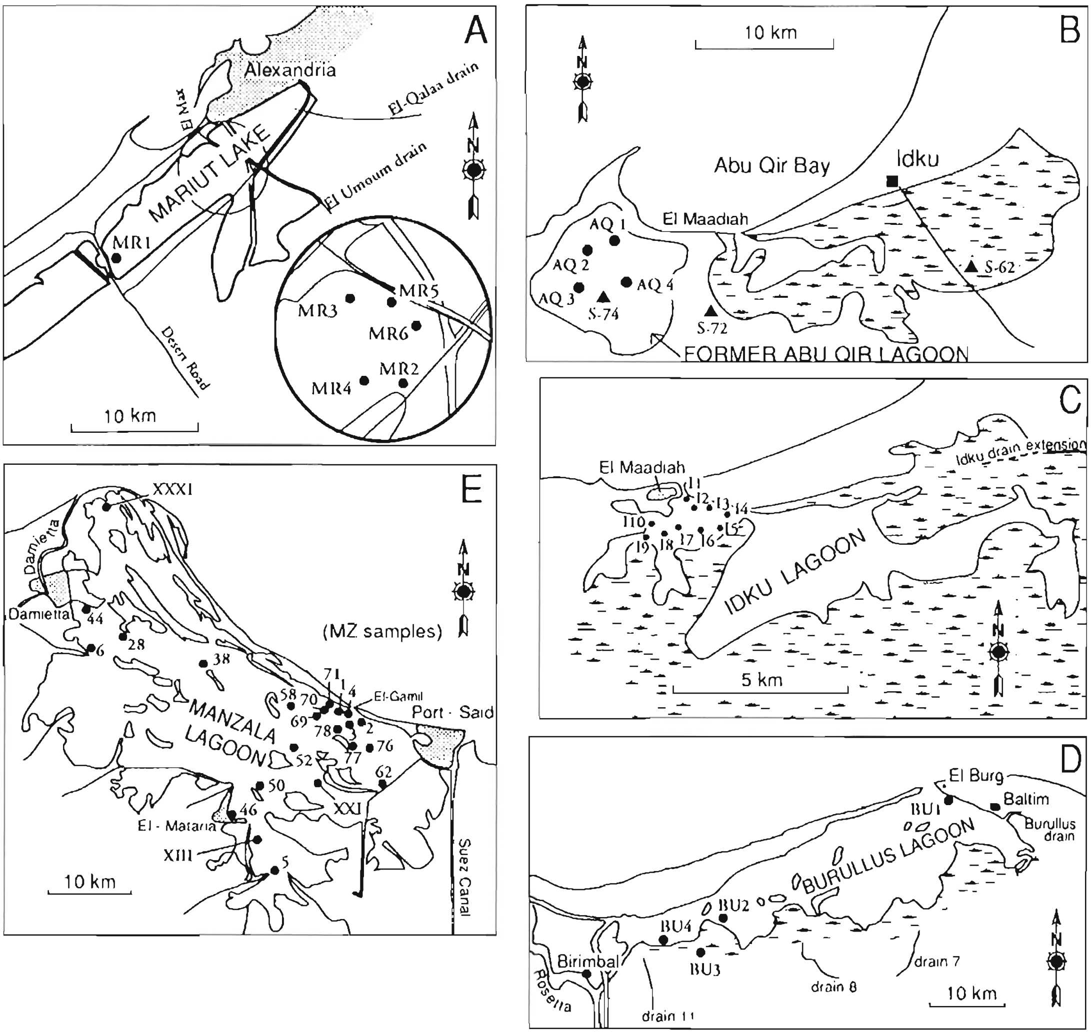

Figure 2. Positions of surficial samples in Mariut lake and three lagoons, short cores in former Abu Qir lagoon (AQ1–AQ4), and long cores (S-62, -72, -74) in the Idku lagoon region. X-radiographs of 3 short cores (MZ-XIII, MZ-XXI and MZ-XXXI) in Manzala lagoon are illustrated in Figure 3.

and 2. The species are listed in systematic order following criteria suggested by MOORE (1969) for the bivalves, and that proposed by WENZ (1938–1944) for the gastropods.

Statistical analysis was performed to define biofacies in the modern Nile lagoon environments. Faunal lists compiled for each of 33 bulk samples from Idku, Burullus and Manzala lagoons (Burullus sample BU3, collected in a marsh, was not considered) provide the basis for a principal component analysis. The data matrix consists of the 33 samples considered as variables (data in vertical columns) and the 46 molluscan species in these lagoon samples as observations (data in horizontal rows). The numbers in the matrix are species abundances (Table 1). Following the same procedure, the six Mariut lake samples were added to and treated statistically with the 33 lagoon surficial samples (for a total of 47 species) using the same matrix. The principal component analysis was performed on a Macintosh LC personal computer using StatView 512+© software.

DEFINING LAGOON SUBFACIES: GENERAL CONSIDERATIONS

Lagoon deposits constitute the dominant sedimentary facies of Holocene age in the northern Nile delta (STANLEY and WARNE, 1993). On the basis of comprehensive compositional analysis of the sand-size fraction, it is readily possible to distinguish sands in modern Nile delta lagoon facies from sands in desert, river and various coastal deposits with which they interfinger (STANLEY and CHEN, 1991). Lagoon deposits can also be differentiated from associated marsh facies on the basis of organic content (DOMINIK and STANLEY, 1993; SIEGEL *et al.*, 1993) and plant matter (HOWA and STANLEY, 1991). Moreover, composition of sand and coarse silt fractions serves to differentiate two lagoon sub-types, essentially biogenic- and terrigenous-rich.

Grain size, staining and surface texture attributes of the sand fraction (FRIHY and STANLEY, 1987), on the other hand, are not sufficiently significant criteria to define modern Nile delta lagoon facies. Nor does statistical analysis of the composition of the sand-size fraction in subsurface mud and sand sequences, alone, suffice to distinguish lagoon from associated deltaic facies in the Nile delta (FRIHY and STANLEY, 1988). These difficulties result, in part, from effects of extensive sediment reworking and mixing due to transport processes, and also from effects of both fluvial and marine influences which often occur within a single lagoon. To resolve this process-related problem, definition of Nile lagoon facies in subsurface Holocene sequences requires taking into account sedimentary and biogenic structures along with textural and compositional attributes (LOIZEAU and STANLEY, 1993). This comprehensive approach serves to more clearly define lagoon deposits, and also to differentiate marine- from fluvial-influenced variants (ARBOUILLE and STANLEY, 1991; CHEN *et al.*, 1992; STANLEY *et al.*, 1992; WARNE and STANLEY, 1993).

It is recognized that the biogenic content of Nile lagoon deposits tends to be higher than in other facies (COUTELLIER and STANLEY, 1987; STANLEY and CHEN, 1991), and this component usually includes a statistically large proportion of mollusc shells and shell fragments (often stratified, Figure 3), as well as polychaetes, ostracods (PUGLIESE and STANLEY, 1991), foraminifera (KULYK, 1987) and plant debris (HOWA and STANLEY, 1991). A diverse suite of petrological subfacies in Idku lagoon, including some that are biogenic-rich, has recently been identified by analyses of surficial and subsurface deposits (in short cores). The approach used integrates data on lithology, physical and biogenic structures, grain size and composition of the sand-size fraction (LOIZEAU and STANLEY, 1993).

MOLLUSC DISTRIBUTIONS AND INTERPRETATIONS

General

A total of 47 mollusc species in the 34 surficial lagoon and 6 lake samples, represented by 66,224 specimens (Table 1), were identified. These include 21 bivalves and 26 gastropods (Tables 1 and 2). All taxa have been previously cited in the Mediterranean area, and most are also described in the literature. An autoecological investigation made for each of the 47 species (LONGO, 1992) includes their environmental setting, ecological meaning, life-habit and feeding type (these are summarized in Table 3). Ecological meaning refers to affinity of a species to a precise biocoenosis, as defined by modern bionomists working on Mediterranean faunas (PERES and PICARD, 1964; PICARD, 1965; GUELORGET and PERTHUISOT, 1983). Ecological meaning codes used in Table 3 refer to both marine and lagoon taxa. On the basis of all the above available information, it is possible to assign a fresh-water, lagoon proper or marine setting to 41 of the 47 species (Table 3).

Cumulative dominance values of these three environmental settings have been calculated, taking into account the entire molluscan fauna in each of the 40 samples. Relative percentages of fresh-water influenced, lagoon *sensu stricto* (*s.s.*) and marine influenced assemblages for all samples in the three lagoons and Mariut lake are depicted in Figure 4. There is considerable variability of faunas within and between water bodies: Manzala comprises samples with a large proportion of marine, and some with high percentages of fresh-water species; Idku, Burullus and Mariut thanatocoenoses are dominated by lagoon *s.s.* taxa, although of variable proportions. This variability is the result, in part, of an uneven sampling net with respect to both sample spacing and geographic setting (Figure 2). Some of the factors which result in sample variability depicted in Figure 4 are discussed in the following sections.

Idku Lagoon

Idku, smallest of the three lagoons, is located in the northwestern part of the delta, south and

Table 1. *Abundance of mollusc species in surficial samples of Mariut lake and Idku, Burullus and Manzala lagoons in the northern Nile delta of Egypt.*

	Mariut						Idku										Burullus	
	MR1	MR2	MR3	MR4	MR5	MR6	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	BU1	BU2
Bivalvia																		
Glycymeris sp.	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Brachidontes (*B.*) *variabilis*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Musculus costulatus	—	—	—	—	—	—	3	1	—	—	—	—	1	—	—	—	—	—
Pinctada radiata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ostrea edulis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12	—
Ostrea sp.	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—
Loripes lacteus	34	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
Laevicardium (*L.*) *oblongum*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cerastoderma glaucum	108	38	23	28	1	—	41	5	15	76	44	65	32	26	139	82	58	31
Mactra (*M.*) *corallina*	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Macoma (*M.*) *cumana*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Donax (*D.*) *semistriatus*	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
Donax (*D.*) *venustus*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Donax (*Serrula*) *trunculus*	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—
Abra ovata	203	178	52	140	—	—	26	1	4	78	52	92	38	70	300	47	163	—
Pharus legumen	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mytilopsis sp.	1	17	5	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Corbicula (*C.*) *fluminalis*	—	—	6	—	—	—	19	—	7	18	2	1	—	—	—	—	—	—
Venerupis aurea	18	—	—	—	—	—	1	—	—	—	—	—	1	—	1	2	—	—
Chamelea gallina	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Barnea candida	—	—	—	—	—	—	1	—	—	—	—	1	—	2	3	3	—	—
Gastropoda																		
Diodora sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Gibbula sp.	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
Theodoxus (*Neritaea*) *niloticus*	—	268	15	3	31	78	—	—	—	—	—	—	—	—	—	—	—	—
Bellamya unicolor	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lanistes carinatus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Valvata nilotica nilotica	—	—	—	—	—	—	—	1	2	3	3	—	—	—	—	—	—	—
Hydrobia stagnorum	36	10,213	3,389	4,244	261	419	30	6	13	124	216	1,034	440	816	2,930	203	6,010	429
Gabbiella cf. *senaariensis*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cleopatra bulimoides	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	1
Melanoides tuberculata	1	753	729	720	6	24	22	14	95	250	78	96	71	49	65	105	129	1
Potamides conicus	4	328	111	88	1	—	4	—	1	6	10	26	33	3	69	4	1,062	—
Bittium (*B.*) *reticulatum*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bittium sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Neverita josephinia var. *aegyptiaca*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sphaeronassa mutabilis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Hinia pygmaea	—	—	—	—	—	—	—	—	—	1	—	1	—	1	1	1	—	—
Hinia reticulata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Turbonilla gradata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Haminoea navicula	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—
Ferrissia isseli	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Physa acuta	—	2	1	—	4	2	—	1	—	—	—	—	—	—	—	—	—	—
Lymnaea (*Radix*) cf. *natalensis*	—	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—	—	—
Segmentorbis (*S.*) *angustus*	—	—	—	—	—	—	1	—	—	1	1	—	1	—	—	—	—	—
Bulinus truncatus	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—
Biomphalaria alexandrina	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Planorbis planorbis	—	69	36	15	52	84	4	1	—	4	10	2	2	3	6	—	—	—
Total	405	11,867	4,367	5,240	356	607	156	31	140	562	420	1,319	620	971	3,514	447	7,434	464

Table 1. *Extended.*

	Burullus		Manzala																			
	BU3	BU4	MZ1	MZ2	MZ3	MZ4	MZ5	MZ6	MZ28	MZ38	MZ44	MZ46	MZ50	MZ52	MZ58	MZ62	MZ69	MZ70	MZ71	MZ76	MZ77	MZ78
Bivalvia																						
Glycymeris sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Brachidontes (*B.*) *variabilis*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Musculus costulatus	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	1	4
Pinctada radiata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—
Ostrea edulis	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	9	—	3	64
Ostrea sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Loripes lacteus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Laevicardium (*L.*) *oblongum*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
Cerastoderma glaucum	—	401	186	1	8	—	29	8	11	3	65	70	63	38	266	107	15	181	296	55	690	328
Mactra (*M.*) *corallina*	—	—	8	1	22	1	—	—	—	—	—	—	—	—	—	2	—	3	—	3	2	3
Macoma (*M.*) *cumana*	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—	1	—
Donax (*D.*) *semistriatus*	—	—	4	4	274	29	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
Donax (*D.*) *venustus*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	2	—	—	—
Donax (*Serrula*) *trunculus*	—	—	1	1	6	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Abra ovata	—	421	82	—	9	—	12	9	4	1	24	106	29	5	61	42	25	160	389	83	346	132
Pharus legumen	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mytilopsis sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Corbicula (*C.*) *fluminalis*	23	85	—	—	—	—	104	5	6	—	3	126	59	95	12	3	1	3	7	—	—	—
Venerupis aurea	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	6	4
Chamelea gallina	—	—	—	2	4	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	5	—
Barnea candida	—	1	—	—	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—
Gastropoda																						
Diodora sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Gibbula sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Theodoxus (*Neritaea*) *niloticus*	—	25	—	—	—	—	3	6	—	—	5	2	2	61	261	6	—	—	3	—	—	—
Bellamya unicolor	—	4	—	—	—	—	—	—	—	—	—	23	4	—	—	1	—	—	—	—	—	—
Lanistes carinatus	5	1	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Valvata nilotica nilotica	—	67	—	—	—	—	—	39	33	—	—	10	—	—	—	—	—	—	—	—	—	—
Hydrobia stagnorum	—	860	755	—	—	—	—	10	7	1	4	3	—	6	79	24	83	1.453	1,812	429	8,019	1,880
Gabbiella cf. *senaariensis*	—	7	—	—	—	—	1	—	—	—	—	3	4	—	—	—	—	—	—	—	—	—
Cleopatra bulimoides	11	6	—	—	—	—	2	—	—	—	—	4	—	2	—	—	—	—	—	—	—	—
Melanoides tuberculata	2	200	66	—	—	—	46	11	19	3	20	163	41	180	83	158	11	53	192	67	89	37
Potamides conicus	—	8	149	1	3	1	—	2	18	3	7	8	99	189	97	146	10	317	561	27	920	260
Bittium (*B.*) *reticulatum*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—
Bittium sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	1	—	—	—	2
Neverita josephinia var. *aegyptiaca*	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sphaeronassa mutabilis	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Hinia pygmaea	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Hinia reticulata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—
Turbonilla gradata	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Haminoea navicula	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Ferrissia isseli	—	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Physa acuta	—	37	—	—	—	—	2	—	3	—	—	6	—	2	7	2	—	—	—	—	—	—
Lymnaea (*Radix*) cf. *natalensis*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Segmentorbis (*S.*) *angustus*	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bulinus truncatus	—	45	—	—	—	—	—	2	—	—	—	1	1	—	3	—	—	—	—	—	—	—
Biomphalaria alexandrina	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—
Planorbis planorbis	—	76	—	—	—	—	2	42	20	6	6	9	—	2	885	11	4	11	1	—	—	—
Total	41	2,250	1.253	12	334	37	201	136	121	17	135	536	305	580	1,756	503	152	2,186	3,273	666	10,089	2,721

Table 2. *Dominance values of mollusc species in surficial samples of Mariut lake, and Idku, Burullus and Manzala lagoons in the northern Nile delta of Egypt. Explanation in text.*

	Mariut						Idku										Burullus	
	MR1	MR2	MR3	MR4	MR5	MR6	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	BU1	BU2
Bivalvia																		
Glycymeris sp.	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0	0
Brachidontes (B.) variabilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Musculus costulatus	0	0	0	0	0	0	1.9	3.2	0	0	0	0	0.2	0	0	0	0	0
Pinctada radiata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ostrea edulis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0
Ostrea sp.	0	0	0	0	0	0	0.6	0	0	0	0	0	0	0	0	0	0	0
Loripes lacteus	8.4	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0
Laevicardium (L.) oblongum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cerastoderma glaucum	26.7	0.3	0.5	0.5	0.3	0	26.3	16.1	10.7	13.5	10.5	5.0	5.2	2.7	4.0	18.3	0.8	6.7
Mactra (M.) corallina	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0	0
Macoma (M.) cumana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Donax (D.) semistriatus	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0
Donax (D.) venustus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Donax (Serrula) trunculus	0	0	0	0	0	0	1.3	0	0	0	0	0	0	0	0	0	0	0
Abra ovata	50.1	1.5	1.2	2.7	0	0	16.7	3.2	2.8	13.9	12.4	7.0	6.1	7.2	8.5	10.5	2.2	0
Pharus legumen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mytilopsis sp.	0.2	0.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corbicula (C.) fluminalis	0	0	0.1	0	0	0	12.2	0	5.0	3.2	0.5	0	0	0	0	0	0	0
Venerupis aurea	4.4	0	0	0	0	0	0.6	0	0	0	0	0	0.2	0	0	0.4	0	0
Chamelea gallina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barnea candida	0	0	0	0	0	0	0.6	0	0	0	0	0	0	0.2	0	0.7	0	0
Gastropoda																		
Diodora sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gibbula sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Theodoxus (Neritaea) niloticus	0	2.3	0.3	0	8.7	12.8	0	0	0	0	0	0	0	0	0	0	0	0
Bellamya unicolor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lanistes carinatus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4
Valvata nilotica nilotica	0	0	0	0	0	0	0	3.2	1.4	0.5	0.7	0	0	0	0	0	0	0
Hydrobia stagnorum	8.9	86.1	77.6	81.0	73.3	69.0	19.2	19.3	9.3	22.0	51.4	78.4	71.0	84.0	83.4	45.4	80.8	92.5
Gabbiella cf. *senaariensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cleopatra bulimoides	0	0	0	0	0	0	0	3.2	0.7	0	0	0	0	0	0	0	0	0.2
Melanoides tuberculata	0.2	6.3	16.7	13.7	1.7	3.9	14.1	45.2	67.9	44.5	18.6	7.3	11.4	5.0	1.8	23.9	1.7	0.2
Potamides conicus	1.0	2.7	2.5	1.7	0.3	0	2.5	0	0.7	1.0	2.4	2.0	5.3	0.3	1.9	0.9	14.3	0
Bittium (B.) reticulatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bittium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neverita josephinia var. *aegyptiaca*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeronassa mutabilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hinia pygmaea	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0.1	0	0	0	0
Hinia reticulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Turbonilla gradata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haminoea navicula	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0
Ferrissia isseli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physa acuta	0	0	0	0	1.1	0.3	0	3.2	0	0	0	0	0	0	0	0	0	0
Lymnaea (Radix) cf. *natalensis*	0	0	0	0	0	0	0.6	0	0	0	0	0	0.1	0	0	0	0	0
Segmentorbis (S.) angustus	0	0	0	0	0	0	0.6	0	0	0.2	0.2	0	0.1	0	0	0	0	0
Bulinus truncatus	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0
Biomphalaria alexandrina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planorbis planorbis	0	0.6	0.8	0.3	14.6	13.8	2.5	3.2	0	0.7	2.4	0.1	0.3	0.3	0.2	0	0	0

Table 2. *Extended.*

	Burullus		Manzala																			
	BU3	BU4	MZ1	MZ2	MZ3	MZ4	MZ5	MZ6	MZ28	MZ38	MZ44	MZ46	MZ50	MZ52	MZ58	MZ62	MZ69	MZ70	MZ71	MZ76	MZ77	MZ78
Bivalvia																						
Glycymeris sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brachidontes (*B.*) *variabilis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Musculus costulatus	0	0	0.1	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0.1
Pinctada radiata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ostrea edulis	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	2.3
Ostrea sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
Loripes lacteus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Laevicardium (*L.*) *oblongum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
Cerastoderma glaucum	0	17.8	14.8	8.3	2.4	0	14.4	5.9	9.1	17.6	48.5	13.0	20.7	6.5	15.1	21.3	9.9	8.3	9.0	8.2	6.8	12.0
Mactra (*M.*) *corallina*	0	0	0.6	8.3	6.6	2.7	0	0	0	0	0	0	0	0	0	0.4	0	0.1	0	0.4	0	0.1
Macoma (*M.*) *cumana*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0	0	0
Donax (*D.*) *semistriatus*	0	0	0.3	33.3	82.0	78.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Donax (*D.*) *venustus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.3	0	0	0	0	0
Donax (*Serrula*) *trunculus*	0	0	0	8.3	1.8	5.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Abra ovata	0	18.7	6.5	0	2.7	0	6.0	6.6	3.3	5.9	17.9	19.8	9.5	0.8	3.5	8.3	16.4	7.3	11.9	12.5	3.4	4.8
Pharus legumen	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mytilopsis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corbicula (*C.*) *fluminalis*	56.1	3.8	0	0	0	0	51.7	3.7	5.0	0	2.2	23.5	19.4	16.4	0.7	0.6	0.7	0.1	0.2	0	0	0
Venerupis aurea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1
Chamelea gallina	0	0	0	16.7	1.2	10.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barnea candida	0	0	0	0	0	0	0	0	0	0	0	0.4	0.3	0	0	0	0	0	0	0	0	0
Gastropoda																						
Diodora sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gibbula sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Theodoxus (*Neritaea*) *niloticus*	0	1.1	0	0	0	0	1.5	4.4	0	0	3.7	0.4	0.6	10.5	14.7	1.2	0	0	0.1	0	0	0
Bellamya unicolor	0	0.2	0	0	0	0	0	0	0	0	0	4.3	1.3	0	0	0.2	0	0	0	0	0	0
Lanistes carinatus	12.2	0	0	0	0	0	0	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Valvata nilotica nilotica	0	3.0	0	0	0	0	0	28.7	27.3	0	0	1.9	0	0	0	0	0	0	0	0	0	0
Hydrobia stagnorum	0	38.2	60.3	0	0	0	0	7.5	5.8	5.9	3.0	0.6	0	1.0	4.5	4.8	54.6	66.5	55.7	64.4	79.5	69.1
Gabbiella cf. *senaariensis*	0	0.3	0	0	0	0	0.5	0	0	0	0	0.6	1.3	0	0	0	0	0	0	0	0	0
Cleopatra bulimoides	26.8	0.3	0	0	0	0	1.0	0	0	0	0	0.7	0	0.3	0	0	0	0	0	0	0	0
Melanoides tuberculata	4.9	8.9	5.3	0	0	0	22.9	8.1	15.7	17.6	14.9	30.4	13.5	31.0	4.7	31.4	7.2	2.4	5.9	10.1	0.9	1.4
Potamides conicus	0	0.4	11.9	8.3	0.9	2.7	0	1.5	14.9	17.6	5.2	1.5	32.6	32.6	5.5	29.0	6.6	14.5	17.1	4.0	9.1	9.6
Bittium (*B.*) *reticulatum*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bittium sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0.1
Neverita josephinia var. *aegyptiaca*	0	0	0	16.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeronassa mutabilis	0	0	0	0	0.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hinia pygmaea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
Hinia reticulata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Turbonilla gradata	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haminoea navicula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ferrissia isseli	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physa acuta	0	1.6	0	0	0	0	1.0	0	2.5	0	0	1.1	0	0.3	0.4	0.4	0	0	0	0	0	0
Lymnaea (*Radix*) cf. *natalensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Segmentorbis (*S.*) *angustus*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulinus truncatus	0	2.0	0	0	0	0	0	1.5	0	0	0	0.2	0.3	0	0.2	0	0	0	0	0	0	0
Biomphalaria alexandrina	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0
Planorbis planorbis	0	3.4	0	0	0	0	1.0	30.9	16.5	35.3	4.5	1.7	0	0.3	50.4	2.2	2.6	0.5	0	0	0	0

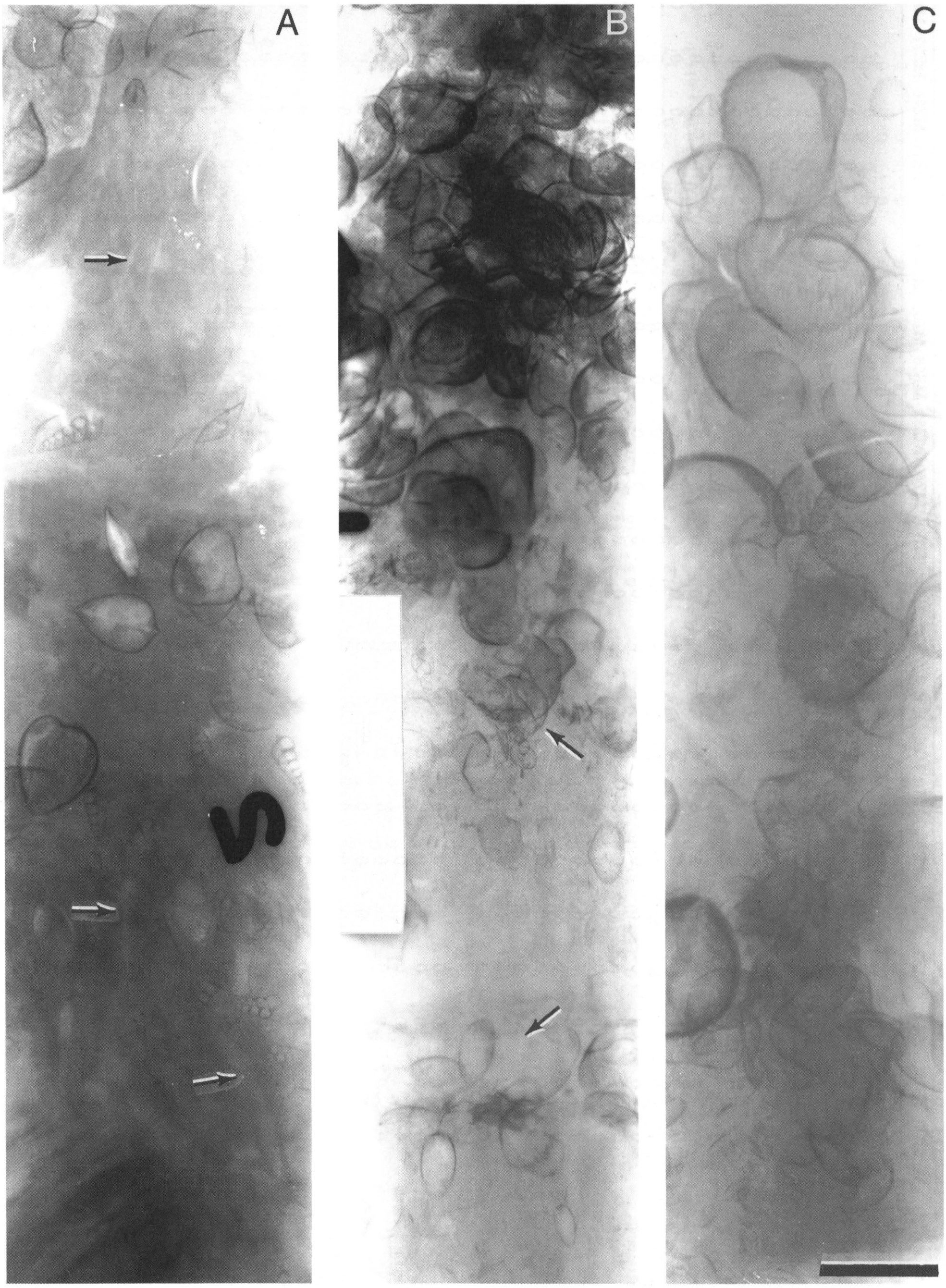

Figure 3. X-radiograph prints of shell-rich layers in selected short cores from Manzala lagoon. A, autochthonous assemblage of articulated bivalves (*Cerastoderma glaucum*) and gastropods (*Potamides conicus*) dispersed in muddy sand; arrows point to burrows (core MZ-XXXI), B, lower section reveals two autochthonous layers (arrows) comprising small articulated pelecypod and gastropod shells scattered in mud; upper section shows the base of a thick (> 30 cm), coquina-like, allochthonous concentration of disarticulated pelecypod valves (core MZ-XIII). C, allochthonous layer of large, disarticulated valves of *Cerastoderma glaucum,* dispersed in sandy mud (core MZ-XXI). Bar scale in C = 2 cm.

Table 3. *Autoecological attributes of molluscan species (taxa are listed in systematic order).*

	Environmental Setting	Ecological Meaning	Life-habit	Feeding Type
Bivalvia				
Glycymeris sp.	UNDET		VAG INF	SUSPENSION
Brachidontes (*B.*) *variabilis*	LAGOON	LEE	ATT EPIF	SUSPENSION
Musculus costulatus	MARINE	SSPR	ATT EPIF	SUSPENSION
Pinctada radiata	MARINE	SSPR	ATT EPIF	SUSPENSION
Ostrea edulis	MARINE	SSPR	ATT EPIF	SUSPENSION
Ostrea sp.	UNDET		ATT EPIF	SUSPENSION
Loripes lacteus	MARINE	SVMC	VAG INF	SUSPENSION
Laevicardium (*L.*) *oblongum*	MARINE	DC	VAG INF	SUSPENSION
Cerastoderma glaucum	LAGOON	LEE	VAG INF	SUSPENSION
Mactra (*M.*) *corallina*	MARINE	SFBC	VAG INF	SUSPENSION
Macoma (*M.*) *cumana*	MARINE	SFBC	VAG INF	DETRITUS
Donax (*D.*) *semistriatus*	MARINE	SFHN	VAG INF	SUSPENSION
Donax (*D.*) *venustus*	MARINE	SFBC	VAG INF	SUSPENSION
Donax (*Serrula*) *trunculus*	MARINE	SFHN	VAG INF	SUSPENSION
Abra ovata	LAGOON	LEE	VAG INF	DETRITUS
Pharus legumen	MARINE	SFBC	VAG INF	SUSPENSION
Mytilopsis sp.	UNDET		ATT EPIF	SUSPENSION
Corbicula (*C.*) *fluminalis*	FRESH WATER		ATT EPIF	SUSPENSION
Venerupis aurea	MARINE	SVMC	VAG INF	SUSPENSION
Chamelea gallina	MARINE	SFBC	VAG INF	SUSPENSION
Barnea candida	MARINE	SFBC	VAG INF	SUSPENSION
Gastropoda				
Diodora sp.	UNDET		VAG EPIF	SCRAPER
Gibbula sp.	UNDET		VAG EPIF	SCRAPER
Theodoxus (*N.*) *niloticus*	FRESH WATER		VAG EPIF	BROWSER
Bellamya unicolor	FRESH WATER		VAG EPIF	BROWSER
Lanistes carinatus	FRESH WATER		VAG EPIF	BROWSER
Valvata nilotica nilotica	FRESH WATER		VAG EPIF	BROW/SCRA
Hydrobia (*H.*) *stagnorum*	LAGOON	LEE	VAG EPIF	BROWSER
Gabbiella cf. *senaariensis*	FRESH WATER		VAG EPIF	BROW/SCRA
Cleopatra bulimoides	FRESH WATER		VAG EPIF	SCRAPER
Melanoides tuberculata	FRESHW/LAGOON		VAG EPIF	SCRAPER
Potamides conicus	LAGOON	LEE	VAG EPIF	SCRAPER
Bittium (*B.*) *reticulatum*	MARINE	HP/AP	VAG EPIF	BROWSER
Bittium sp.	UNDET		VAG EPIF	BROWSER
Neverita josephinia	MARINE	SFBC	VAG INF	CARNIVORE
Sphaeronassa mutabilis	MARINE	SFBC	VAG INF	CARNIVORE
Hinia pygmaea	MARINE	SFBC	VAG INF	CARNIVORE
Hinia reticulata	LAGOON	LEE	VAG INF	CARNIVORE
Turbonilla gradata	MARINE	SSPR	VAG EPIF	PARASITE
Haminoea navicula	MARINE	SSPR	VAG EPIF	BROWSER
Ferrissia isseli	FRESH WATER		VAG EPIF	SCRAPER
Physa acuta	FRESH WATER		VAG EPIF	BROWSER
Lymnaea natalensis	FRESH WATER		VAG EPIF	BROWSER
Segmentorbis angustus	FRESH WATER		VAG EPIF	SCRAPER
Bulinus (*Isidora*) *truncatus*	FRESH WATER		VAG EPIF	SCRAPER
Biomphalaria alexandrina	FRESH WATER		VAG EPIF	SCRAPER
Planorbis planorbis	FRESH WATER		VAG EPIF	BROWSER

Abbreviations are: AP = Biocoenosis of Photophilous Algae; ATT EPIF = attached epifaunal; DC = Biocoenosis of Coastal Detritic Bottoms; HP = Biocoenosis of Posidonia Meadows; LEE = Biocoenosis of Euryhaline and Eurytherm Lagoons; SFBC = Biocoenosis of Fine Well Sorted Sands; SFHN = Biocoenosis of Surficial Fine Sands; SSPR = no precise ecological meaning; SVMC = Biocoenosis of Surficial Muddy Sands in Sheltered Areas; UNDET = undetermined; VAG EPIF = vagile epifaunal; VAG INF = vagile infaunal

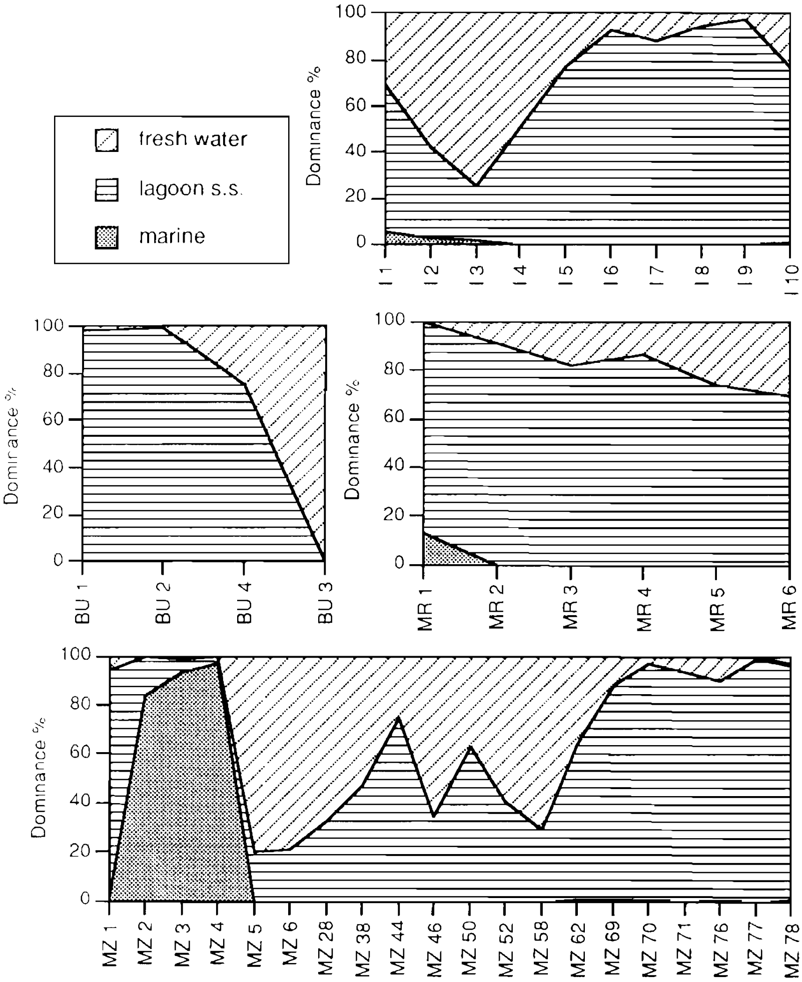

Figure 4. Dominance percentages of fresh-water, lagoon *s.s.* and marine influenced molluscan assemblages in 40 surficial samples collected in the four modern water bodies of the Nile delta.

east of the town of El Maadiah (Figure 2C). It is ~27 km long and has a maximum width of 10 km. It presently consists of two almost separate, open water basins (LOIZEAU and STANLEY, 1993); these cover a total area of 18 km^2, and are connected to the Mediterranean by a narrow channel opened along the northern margin of the lagoon. This outlet is located at its northwestern sector at the town of El Maadiah. Along its southern and eastern margins, the lagoon is bordered by extensive marshes comprising aquatic macrophytic plants. Much of the fresh water reaching the lagoon is fed by an extension of Idku drain, flowing from east to west, and also by irrigation channels flowing to the basins from the south. Water depth ranges from about 0.5 to 1.5 m, and chlorinity from 0.48 to 2.0 g/l (SAAD, 1976b). Ten samples (coded I) were collected in the shallower and relatively more saline western basin (Figure 2C).

Molluscan thanatocoenoses are characterized by vagile epifaunal herbivore (scraper and browser) taxa, except for the assemblage of sample I1 (collected in the outlet proper) where vagile infaunal suspension and detritus feeders are better represented, accompanied by a small percentage of attached epifauna (Tables 2 and 3). Six samples (I5 to I10), aligned east to west at about 700 m south of the outlet, contain large proportions of lagoon *s.s.* taxa (Figure 4). Samples I2 to I4, collected close to the outlet in the northeastern sector of the western basin, record a high percentage of fresh-water molluscs. Marine species are present, with a negligible cumulative dominance (Figure 4) in samples I1 and I2 (Tables 2 and 3).

This faunal distribution was unexpected, for there is a greater cumulative dominance of fresh-water taxa in samples closest to the outlet and sea. It appears that the influence of land-derived water is stronger than the marine in this part of the western basin. This is probably related, at least in part, to important fresh-water input by Idku drain which then flows from east to west along the northern lagoon margin. The small cumulative dominance of vagile epifauna in sample I1 is primarily a function of strong, predominant outflow from lagoon to sea as recorded in and near the outlet (LOIZEAU and STANLEY, 1993). Proportions of such vagile epifauna species would be reduced in the vicinity of the outlet, where strong bottom current conditions prevail.

Burullus Lagoon

Burullus, second largest of the coastal lagoons, is located in the north-central part of the delta plain and occupies much of the area between the Rosetta branch of the Nile and the town of Baltim (Figure 2D). It is ~55 km long and reaches a maximum width of 14 km (KERAMBRUN, 1986). The outlet to the Mediterranean is located at its northeastern margin just west of the town of El Burg. The southern margin is bordered by both submergent and emergent marshes, the former being better developed in the southeastern sector and the latter in the southwestern one (ARBOUILLE and STANLEY, 1991). The lagoon receives fresh water from numerous drains along the southern and eastern margins; among the more important is Burullus drain, which discharges into the eastern part of the lagoon, southeast of the outlet. Water depth ranges from 0.1 to 2.4 m, and chlorinity from 0.32 to 2.4 g/l (SAAD, 1976a). Four samples (coded BU) were collected: one in the eastern sector close to the outlet; two in the western part distant 30 and 40 km, respectively, from the outlet; and one from the southwestern marsh area (Figure 2D).

Molluscan thanatocoenoses are mainly composed of vagile epifaunal species accompanied by a few representatives of both attached epifauna (BU3) and endofauna (BU4). Herbivores prevail in samples BU1, BU2 and BU4 and, among them, browsers account for greatest cumulative dominance values. Suspension feeders are important in sample BU3 (Tables 2 and 3). Only lagoon *s.s.* and fresh-water species are observed in this lagoon (Figure 4). There is a gradual increase in fresh-water taxa with increasing distance from the outlet. Sample BU3, collected in the marsh, is composed entirely of fresh-water molluscan species. The negligible influence of the sea in Burullus lagoon is denoted by the absence of marine species, even in sample BU1 positioned close to the outlet.

Manzala Lagoon

Manzala, largest of the delta lagoons, is located in the northeastern part of the delta plain. It occupies the region between Damietta branch of the Nile to the west, and Suez Canal and Port Said to the east (Figure 2E). This water body is generally rectangular in shape, with a length of ~49 km, maximum width of 29 km, and an area of about 450 km^2 (RANDAZZO, 1992). The major outlet to the sea, at El-Gamil, lies about 8 km west of Port Said. Periodic incursions from the sea into the lagoon occur primarily during winter, resulting in part from washover events in the northwestern sector of the lagoon. Storm waves, occasionally cresting to ~2 m, are sometimes driven landward over and across the low-lying sand ridges which separate the lagoon from the sea. As in Idku and Burullus, emergent and submergent marshes (Figure 5B) border the margins and also the numerous islets in the lagoon. Manzala receives fresh water from a series of drains, some of them very large, which discharge along its western, southern and eastern margins; these latter include some channel connections with the Suez Canal and Port Said area. Water depth does not exceed 1.8 m, and averages 1.2 m (Figure 5A). The chlorinity varies according to locality and season from 0.77 to 11.67 g/l (KERAMBRUN, 1986). Twenty samples were collected (coded MZ), 4 near El-Gamil outlet and 16 along two transects (Figure 2E). Ten of the 16 MZ samples were taken along a NW–SE transect (parallel to the coast), and the other six along a SW–NE transect (perpendicular to the coast).

Molluscan thanatocoenoses are mainly characterized by vagile epifaunal species (Tables 2 and 3). Infauna is prevalent in only four samples, *i.e.*, near the outlet (MZ2 and MZ4) and in the northwesternmost sample (MZ44). From a trophic point of view, the fauna, including seven feeding types,

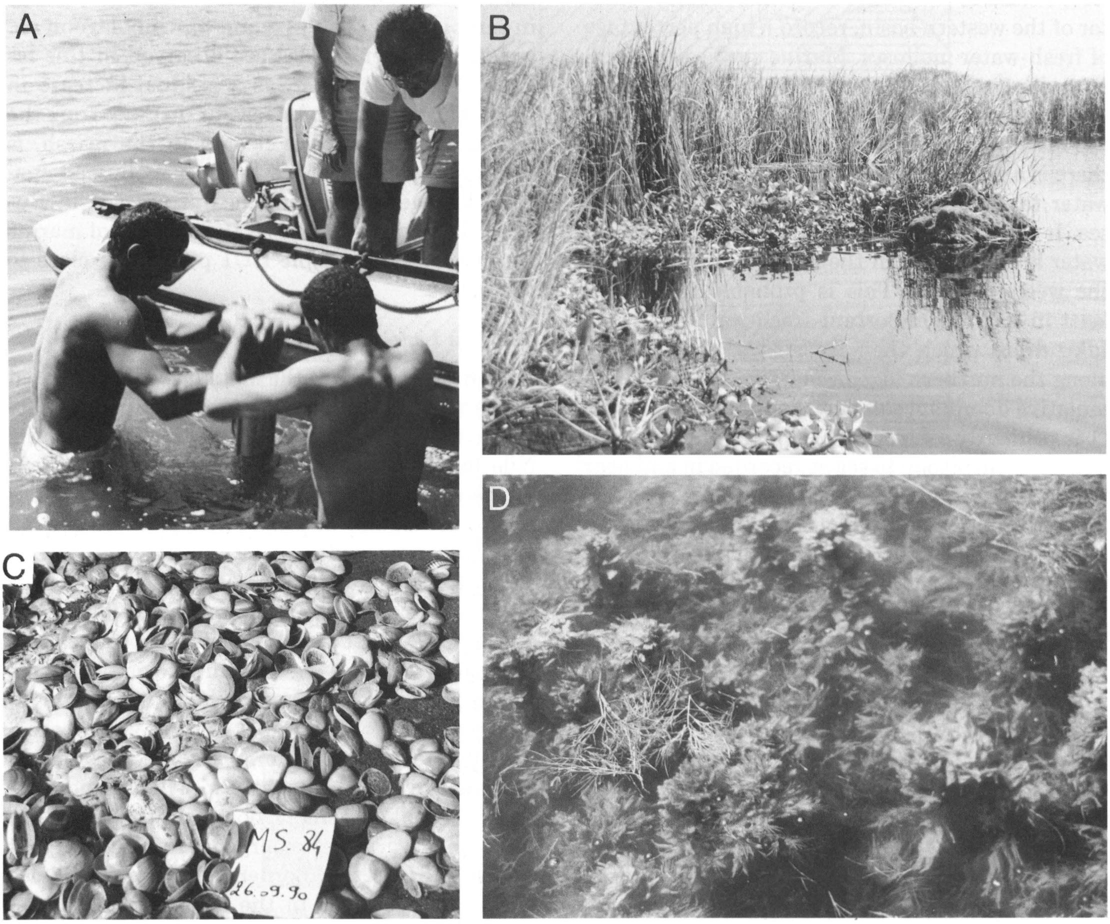

Figure 5. Selected photographs of Manzala lagoon region. A, recovering short core at about 1 m depth; B, phragmites and water hyacinths in marsh on western border of lagoon; molluscan assemblages in this sector record fresh-water influence; C, concentration of open marine nearshore molluscs (mostly *Mactra corallina*) on sand lagoon margin, near El-Gamil outlet; D, view of dense underwater vegetation covering the floor of the west-central sector of the lagoon.

is more diversified than in the two other lagoons. Among these are herbivores (scrapers and browsers) which are dominant over much of the lagoon (15 samples), a large part of which is floored by vegetation (Figure 5D). Exceptions occur in the northwesternmost and southeasternmost sectors (MZ44, MZ5) and in the area close to the outlet, in proximity to the sea (MZ2 to MZ4); suspension feeders are important in these five samples. The other four trophic groups (Table 3) have negligible cumulative dominance values (Table 2). Three different assemblage groupings, indicative of three environmental settings (Figure 4), are distinguished. Thanatocoenoses collected closest to the outlet are composed primarily of marine species (MZ2 to MZ4). Lagoon *s.s.* taxa prevail in samples surrounding the outlet (MZ62, MZ69–MZ71, MZ76–MN78), and in the northernmost sample (MZ44). Fresh-water species comprise up to 50% of cumulative dominance in the remaining samples, most of which were collected in areas more than 800 m distant from the outlet.

Of the mollusc faunas examined in the Nile delta lagoons, those close to El-Gamil outlet in Manzala most clearly record a marine influence (Figures 4 and 5C). This evidence for incursion of Mediterranean water, however, extends only to a small area in proximity of the outlet. The somewhat more marine assemblage in sample MZ44 probably reflects the influence of episodic washover by the sea into this sector of the lagoon, primarily in winter.

Mariut Lake

Mariut, south and southwest of Alexandria, is an enclosed, elongate (NE–SW trending) water body located at the northwesternmost margin of the Nile delta plain (Figure 2A). Presently, there is no natural communication between the lake and the Mediterranean. It is ~25 km long, has a maximum width of 10 km, and is subdivided into more than nine sub-basins by causeways and canals (WARNE and STANLEY, 1993). It receives agricultural drainage water mixed with industrial and municipal wastes (SESTINI, 1992; LOIZEAU and STANLEY, 1994), in particular from the El-Qalaa drain, a westward extension of the large El Mahmudiya canal. The El Mex pumping station, west of Alexandria center, discharges surplus water from the lake to the sea, maintaining lake level at about 2.8 m below sea level. Water depth ranges from 0.9 to 1.5 m (KERAMBRUN, 1986), and chlorinity in the eastern sector of the lake from 0.73 to 19.89 g/l (SAAD *et al.*, 1984). Salinity increases dramatically in the central sub-basin where commercial salt ponds are developed: portions of the elongate western extension of Mariut are sabkha-like (ALI and WEST, 1983). Only two of the sub-basins are actually open water lakes (*cf.* WARNE and STANLEY, 1993): one occupies the northeastern part of Mariut, and the other is SSE of El Mex pumping station. Five samples (coded MR) have been collected in this latter sub-basin (MR2 to MR6), and one (MR1) to the southwest in the salt basin close to the Desert Road (Figure 2A).

Sample MR1, surprisingly, is characterized by vagile infaunal, detritus and suspension feeder taxa of lagoon *s.s.* setting; faunas record only a minor marine influence, and none of fresh water. Assemblages collected at this site, now a commercial salt basin, are older and reworked and not autochthonous faunas. A gradual increase of fresh-water species is observed from sample MR2 to sample MR6, *i.e.*, generally toward the NE and in proximity to El Umoum drain. Molluscan thanatocoenoses are dominated by vagile epifaunal, herbivore (scraper and browser) taxa (Tables 2 and 3) of lagoon *s.s.* setting (Figure 4). Molluscan faunas of eastern Mariut lake, as a whole, are similar to those of the three Nile delta lagoons (Figure 4). Moreover, they comprise a lower proportion of fresh-water faunas than might be expected in a lake setting.

DISTINGUISHING LAGOON MOLLUSCAN BIOFACIES

A principal component analysis was initially performed taking into consideration the 46 species present in the 33 surficial lagoon samples. Only the first two major factors, together accounting for 28.5% of cumulative variance, have been considered herein. This is depicted graphically in an unrotated orthogonal plot (available from the authors), where lagoon samples are clearly separated in three distinct groups.

In the previous section it was shown that faunas from surficial samples in Mariut lake appear generally similar to those of the lagoons (Figure 4). To quantitatively verify the similarity, faunal data from the six Mariut lake samples were thus added to those from the 33 lagoon samples and treated statistically together (47 species in 39 samples). As shown in the unrotated orthogonal plot (Figure 6), three distinct clusters (coded A, B, C) are differentiated, and the six lake samples group well within two of these, *i.e.* B and C.

By taking into account the complete faunal list and ecological meaning of each species (Table 3), the two major factors can be interpreted. Factor 1 refers to dominance of *Hydrobia stagnorum* (Table 2); and Factor 2 to dominance of fresh-water species (the 14 taxa listed in Table 3). The dominance of the two factors is illustrated graphically in Figure 7, where samples are listed in order of increasing values for each of the two factors. This figure also shows the assignment of each of the 39 samples to the three clusters (A, B, C) identified in Figure 6.

These three groups, A, B and C, define lagoon molluscan biofacies (Figure 7): A = lagoon with marine influence (total of 3 samples); B = lagoon with fresh-water influence (15 samples); and C = lagoon *s.s.* (21 samples). Faunal composition of the biofacies, listing mean dominance values, is shown in Table 4. Percentage values listed below refer to dominance. Biofacies A is characterized by >80% marine species, associated with 20% or less of lagoon *s.s.* taxa (but no *Hydrobia stagnorum*), and an absence of fresh-water species. Biofacies B is characterized largely by fresh-water taxa of highly variable proportions (0 to 80%) associated with lagoon *s.s.* taxa of which *H. stagnorum* never exceeds 25%; marine taxa are present, but in low proportions (0–13%). Biofacies C

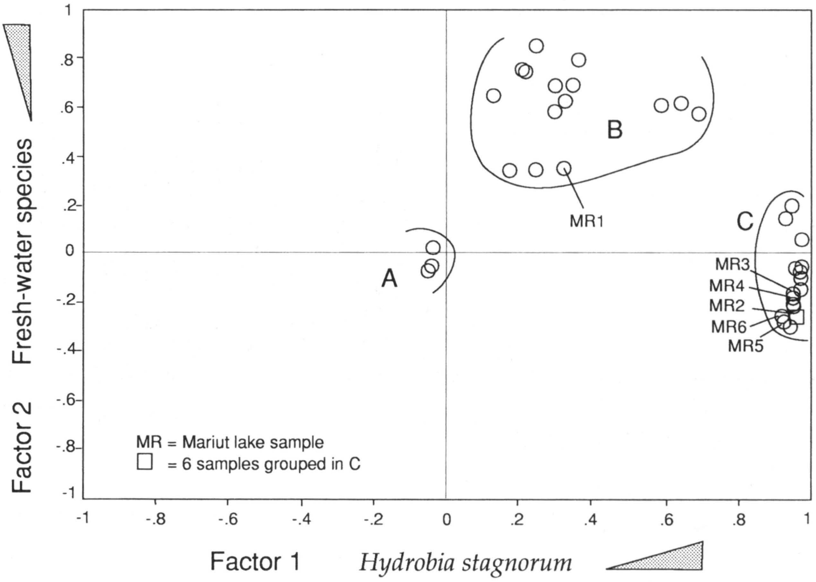

Figure 6. Unrotated orthogonal plot showing two principal components. Factor 1 = dominance of *Hydrobia stagnorum*; Factor 2 = dominance of fresh-water species. This analysis groups molluscan assemblages in 39 surficial samples (including those of Mariut lake) into three clusters corresponding to molluscan biofacies A, B and C.

is dominated (> 70%) by lagoon *s.s.* taxa, of which *H. stagnorum* accounts for >40% of all species counted; fresh-water (to 30%) and marine (to ~3%) taxa are present, but usually in low proportions.

Further definition of the three above molluscan biofacies can be derived by considering the dominance variations (Figure 8) of four species (*H. stagnorum, Abra ovata, Cerastoderma glaucum, Potamides conicus*) viewed as exclusive of the lagoon environment (PERES and PICARD, 1964; PICARD, 1965; GUELORGET and PERTHUISOT, 1983). These species are illustrated in TEBBLE (1966), BROWN (1980), SABELLI (1980) and DAMME (1984). In biofacies A (marine influenced), it is of note that these four species, together, account for <17%. Biofacies C (lagoon *s.s.*) is clearly distinguished by dominant values of *H. stagnorum* and very low proportions of the other three taxa. As to biofacies B (fresh-water influenced), the dominance value of any one of the four species does not exceed 50%, *H. stagnorum* is usually the least represented, and *C. glaucum* decreases as the proportion of *H. stagnorum* increases.

Detailed examination reveals that species proportions in five (MZ44, MZ50, MZ62, I1, and MR1) of the 15 samples grouped in biofacies B differ markedly from the other 10. These five samples have relatively low proportions of *H. stagnorum* (samples denoted by asterisk in Figure 7, upper), and they are also characterized by overall higher cumulative proportions (45–77%) of *A. ovata* and *C. glaucum* (Figure 8). These five samples have an affinity with biofacies C in that lagoon taxa are dominant, and fresh-water species, overall, have a low dominance value (B biofacies samples denoted by asterisk in Figure 7, lower). The origin of this B biofacies variant (coded B*) will be discussed in the following section.

DISTRIBUTION AND INTERPRETATION OF MOLLUSCAN BIOFACIES

The distribution of molluscan assemblages (Figure 9) indicates that a large part of Mariut lake and Idku and Burullus lagoons are dominated by biofacies C (lagoon *s.s.*), while Manzala by biofacies B (lagoon with fresh-water influence). Biofacies A (lagoon with marine influence) is the most restricted geographically, being recorded only in sands near the El-Gamil outlet of Manzala lagoon. In marked contrast to the outlet setting of Manzala, biofacies B samples occur near El Maadiah outlet in Idku lagoon, and a biofacies C sample near El Burg outlet in Burullus lagoon.

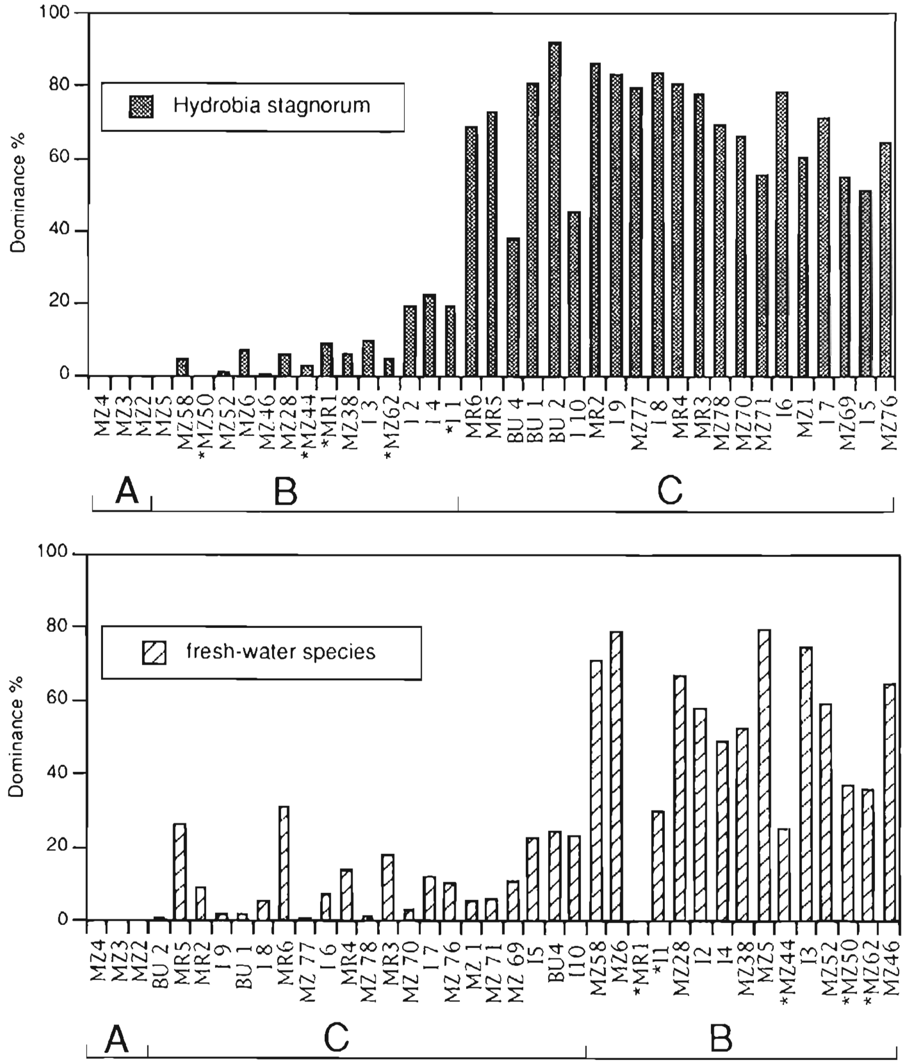

Figure 7. Histograms depicting dominance values of the two major factors shown in Figure 6. Samples are listed in order of increasing values for each of the two factors. Upper, Factor 1 = *Hydrobia stagnorum*; Lower, Factor 2 = fresh-water species. Biofacies A groups 3 samples; biofacies B, 15 samples; and biofacies C, 21 samples. The five samples denoted by asterisk correspond to a biofacies B variant (B*, explanation in text).

Manzala appears to be generally more fresh-water influenced than the other three water bodies (Figure 9). This is probably a response to large volumes of fresh, albeit polluted, water flowing via large drains (Bahr El-Baqar and others) into Manzala (SAAD *et al.*, 1985; SIEGEL *et al.*, 1993). However, our study of faunas in surficial samples also indicates that Manzala is the lagoon with the greatest incursion of marine waters which enter via the outlet, at least seasonally (Figure 9).

In contrast, molluscan biofacies record that the influence of marine waters at the outlets is modest to minimal in both Idku and Burullus lagoons. This is likely a function of relatively large volumes of fresh water which are presently pumped from the Nile delta plain (Figure 10A and B) into irrigation drains and channels (Figure 10C) and, hence, into these lagoons (Figure 10D). As observed in air photos and satellite images, this excess water then tends to flow out of these two lagoons, via their outlets, into the Mediterranean (Figure 11D).

Molluscan faunas (primarily biofacies C) in Mariut lake are primarily of lagoon *s.s.* origin, and statistically comparable to those in the three Nile delta lagoons. Although completely enclosed at present, this water body in the earlier part of the last century was connected at its eastern margin to Abu Qir Bay in the Mediterranean and its surface area was much enlarged compared to the present (ARROWSMITH, 1807; JACOTIN, 1818; WARNE and STANLEY, 1993). The surficial samples we examined, unfortunately, have not been dated. It is thus conceivable that sediment and fauna may have been exposed artificially on the lake floor as a result of recent reworking of bottom sediments by dredging and fishing activity (such as core MR1 recovered in what is presently a salt pool). In this case, faunas could be old and perhaps date back at least to the beginning of last century when Mariut was still a lagoon open to the sea. On the other hand, the surficial assemblages may actually be modern to very young in age, and in this case assemblages would indicate faunas of relict stock (*cf.* PERTHUISOT *et al.*, 1990). Although Mariut is now enclosed, highly polluted (SAAD *et al.*, 1984), and extensively modified by man (WARNE and STANLEY, 1993; LOIZEAU and STANLEY, 1994), its depth, water salinity, temperature and associated flora are comparable in many respects to those of the modern Nile delta lagoons. Thus, it would not be surprising to record moluscs comparable to those living in Idku, Burullus and Manzala.

It is recalled that five samples in Mariut, Idku and Manzala (depicted by asterisk in Figures 7 and 8) are identified as a variant (B*) of biofacies B (fresh-water influenced). Assemblages are characterized by very low values of *H. stagnorum* and high percentages of *A. ovata* and *C. glaucum,* which are taxa of exclusively lagoon origin. These thanatocoenoses likely record special conditions on the lake and lagoon floors. They comprise molluscs that are infaunal, living in bottom sediments, usually mud, covered with minimal and scattered vegetation. Such sectors are characterized by less flora than in most areas (Figure 5D) where molluscs, typically forming biofacies B, thrive.

Table 4. *Faunal composition of molluscan biofacies in the Nile delta. Numbers correspond to mean dominance values.*

	Biofacies		
	A	B	C
Bivalvia			
Glycymeris sp.	—	0.466	—
Brachidontes (B.) variabilis	—	—	0.002
Musculus costulatus	0.100	0.340	0.023
Pinctada radiata	—	—	0.002
Ostrea edulis	0.100	—	0.133
Ostrea sp.	—	0.040	0.004
Loripes lacteus	—	0.560	0.009
Laevicardium (L.) oblongum	—	—	0.004
Cerastoderma glaucum	3.566	17.693	6.742
Mactra (M.) corallina	5.866	0.073	0.057
Macoma (M.) cumana	—	0.013	—
Donax (D.) semistriatus	64.566	0.013	0.014
Donax (D.) venustus	—	—	0.061
Donax (Serrula) trunculus	5.166	0.086	—
Abra ovata	0.900	11.220	6.704
Pharus legumen	0.300	—	—
Mytilopsis sp.	—	0.013	0.009
Corbicula (C.) fluminalis	—	9.573	0.257
Venerupis aurea	—	0.333	0.038
Chamelea gallina	9.566	—	—
Barnea candida	—	0.086	0.042
Gastropoda			
Diodora sp.	—	—	0.002
Gibbula sp.	—	—	0.002
Theodoxus (Neritaea) niloticus	—	2.466	1.204
Bellamya unicolor	—	0.386	0.009
Lanistes carinatus	—	0.100	0.019
Valvata nilotica nilotica	—	4.200	0.176
Hydrobia stagnorum	—	7.453	69.628
Gabbiella cf. *senaariensis*	—	0.160	0.014
Cleopatra bulimoides	—	0.393	0.023
Melanoides tuberculata	—	24.140	7.347
Potamides conicus	3.966	9.706	5.119
Bittium (B.) reticulatum	—	—	0.002
Bittium sp.	—	—	0.038
Neverita josephinia var. *aegyptiaca*	5.566	—	—
Sphaeronassa mutabilis	0.200	—	—
Hinia pygmaea	—	0.013	0.009
Hinia reticulata	—	—	0.002
Turbonilla gradata	0.100	—	—
Haminoea navicula	—	—	0.004
Ferrissia isseli	—	—	0.009
Physa acuta	—	0.593	0.142
Lymnaea (Radix) cf. *natalensis*	—	0.040	0.004
Segmentorbis (S.) angustus	—	0.053	0.014
Bulinus truncatus	—	0.146	0.128
Biomphalaria alexandrina	—	0.020	—
Planorbis planorbis	—	9.946	1.900

To interpret Nile molluscan biofacies, it is useful to consider their overall distribution in light of the paralic ecosystem model of GUELORGET and PERTHUISOT (1983: Figure 19). This model emphasizes biological zonation and the concept of confinement, the latter viewed as the essential factor controlling organism distribution in coastal water bodies. Confinement zones correspond to

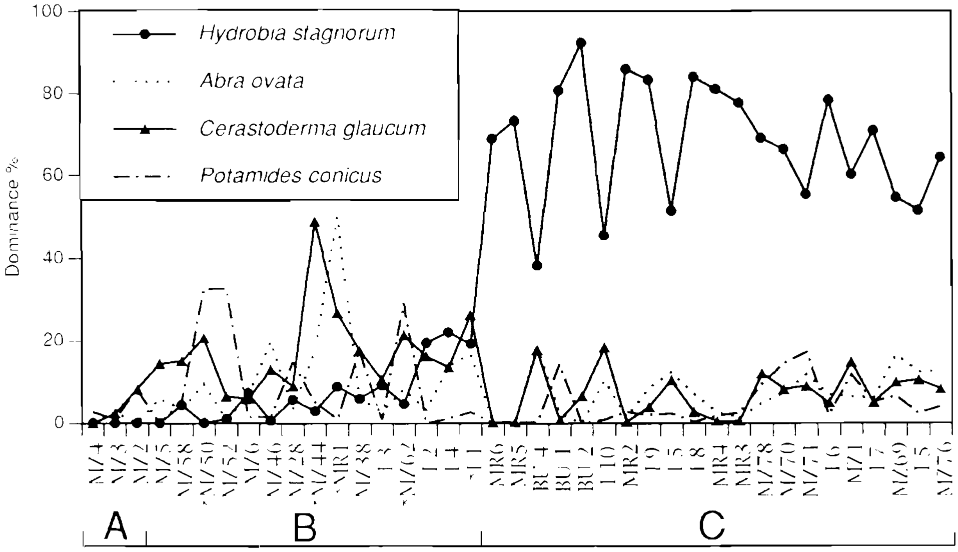

Figure 8. Diagram showing dominance variations of four key species in 39 surficial samples of the Nile delta shallow water bodies. The samples are grouped into molluscan biofacies A, B and C; the five samples denoted by asterisk correspond to the biofacies B variant (B*, explanation in text).

different amounts of time of renewal with marine waters at each given point in a lagoon. In the case of Nile delta lagoons, this would refer largely to the time needed for marine waters to reach from the outlet to inner parts of the water body. Nile delta molluscan biofacies B could be associated with confinement zone VI, biofacies C with zone V, variant B* with zone IV, and A with zone III. These zones, from VI to III as defined by GUELORGET and PERTHUISOT (1983), range to progressively less confined, *i.e.* to sectors with a progressively shorter time of renewal with and/or access to marine water.

FRESH-WATER SPECIES: THEIR SIGNIFICANCE

Modern Nile delta molluscan taxa, as a whole (Tables 1 and 3), as well as the biofacies that they form (Figures 6 to 8), comprise a somewhat larger proportion of fresh-water species than in many other Mediterranean lagoons (FEBVRE, 1968; BARASH and DANIN, 1982; CORSELLI, 1987; CARBONI *et al.*, 1989). The relatively high proportion of fresh-water taxa in Nile delta lagoons is largely a function of the important River Nile water discharge and consequent relatively low salinities. We suggest that this discharge factor is more important than geographic configuration, degree of closure and water exchange patterns between lagoons and open sea (*cf.* KJERFVE and MAGILL, 1989).

In this respect, attention is paid to increased control of River Nile flow by emplacement of the Low Dam at Aswan at the beginning of this century and closure of the High Dam in 1964. Before these dams and barrage construction on the two Nile distributaries, annual Nile flooding in summer and early fall resulted in extensive flushing of the delta plain and marked seasonal input of fresh water into lagoons. However, during periods of low flow, freshwater discharge into lagoons was minimal. This seasonal discharge probably resulted in greater fluctuations in salinities. During the past 30 years, there has been an increase in use of River Nile water between Aswan and the coast for municipal, agricultural and industrial purposes, and since the High Dam and creation of Lake Nasser, there is decreased flow of River Nile water to the delta and sea. It could be envisioned that this decreased fresh-water input to the northern delta would have entrained a concurrent increased marine incursion into the lagoons. This, however, is not the case, and we were initially surprised by our findings which record relatively important proportions of fresh-water taxa in surficial deposits.

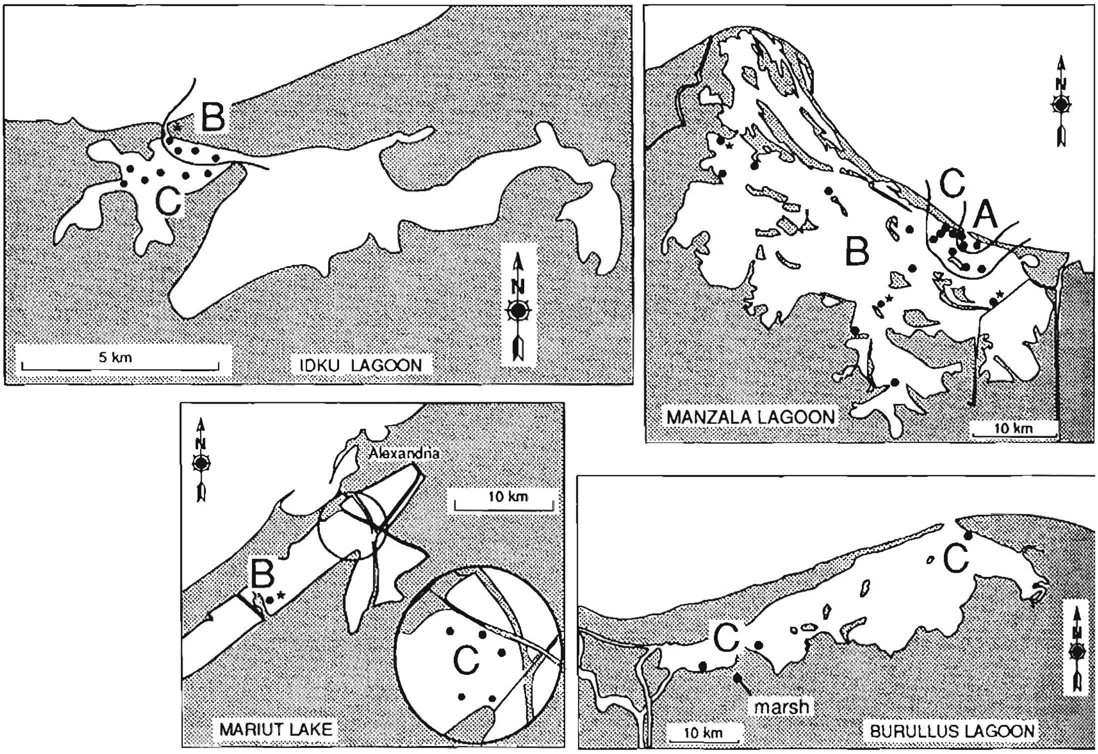

Figure 9. Distribution of the three molluscan biofacies (A, B, C) and variant B* in the four shallow water bodies of the Nile delta.

The total amount of fresh water, much of it polluted, reaching the northern Nile delta has, in fact, decreased. Some of this water, formerly flowing to the sea directly via the Rosetta and Damietta branches of the Nile (Figure 1) is now diverted across the delta plain by a dense network of irrigation channels and drains and pumped into the lagoons (WATERBURY, 1979; SESTINI, 1992; LOIZEAU and STANLEY, 1994). Consequently, there is more fresh water entering these water bodies than a century ago, and an even larger volume after emplacement of the High Dam at Aswan in 1964 (SHAHEEN and YOSEF, 1978; BANOUB, 1979). In addition to the development of an increasingly dense irrigation channel and drain network, the northern delta plain is experiencing large-scale land reclamation projects (WATERBURY, 1979; SESTINI, 1992). These have converted extensive lagoon and wetland areas to aquaculture ponds and farmland (Figures 10A, B and 11A). As a consequence, the lagoons and Mariut lake, now of much reduced size (STANLEY and WARNE, 1993), are receiving a proportionally higher amount of fresh water. Thus, rather than the formerly more direct outflow of Nile waters at the mouth of the two Nile distributaries (INMAN *et al.*, 1976), irrigation waters increasingly are pumped from the delta via the lagoons and their outlets to the Mediterranean (Figure 11D).

Present conditions are expected to continue: delta lagoons of rapidly decreasing size (Figure 11B) will receive a larger proportion of flow from the Nile. As a consequence, we predict that freshwater influenced molluscan biofacies B in the future will become even more widespread in lagoons.

APPLICATION TO THE FOSSIL RECORD

Faunas in Pre-Recent Sequences

Molluscan faunas were previously described in several subsurface core sequences of Holocene age in the northern Nile delta plain (BERNASCONI *et al.*, 1991), but specific lagoon biofacies were not defined. Herein, we apply findings of the present study on modern assemblages to the fossil record of the delta region. In a first phase, we focus on pre-recent lagoon sequences in short cores (40–70

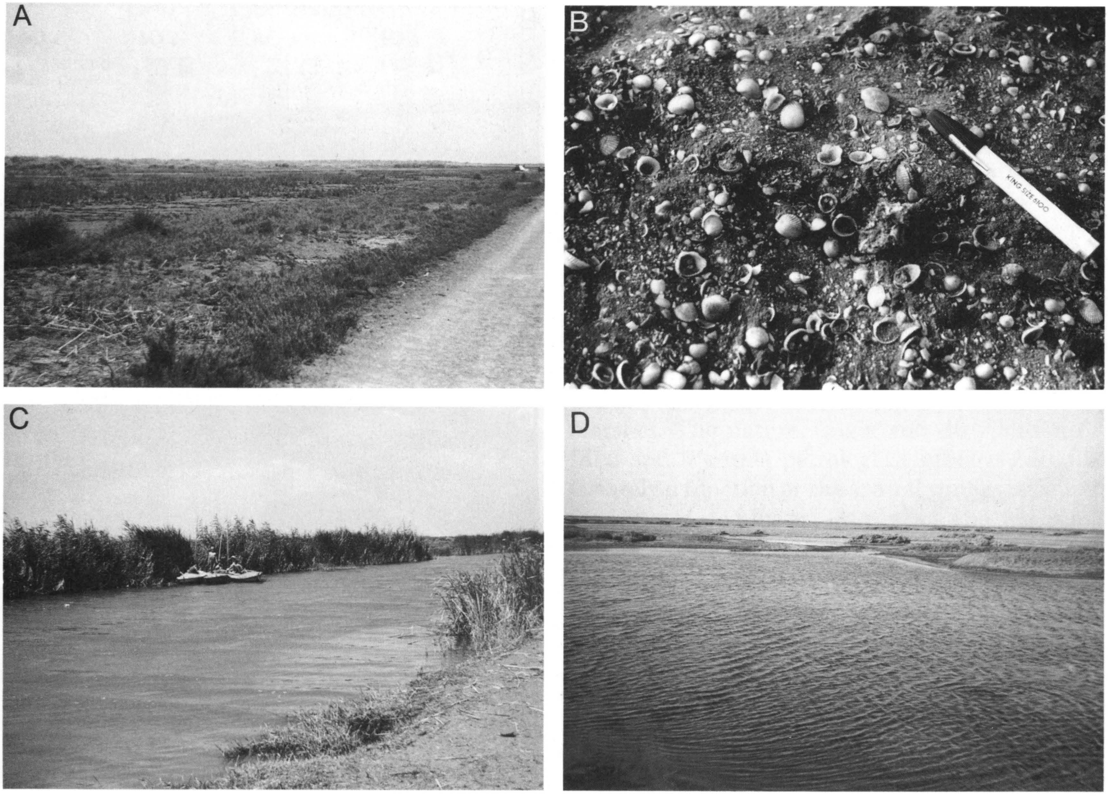

Figure 10. Selected photographs of Burullus lagoon region. A, lagoon surface being drained by pumping; B, recently reclaimed former lagoon surface floored by shell-rich (largely *Cerastoderma glaucum*) sandy mud deposits; C, irrigation channel almost completely filled with water pumped from reclaimed lagoon surface; and D, sediment, some derived from drainage channels, accumulating as islets on southern lagoon margin.

cm), dated from about 200 years ago to the present. This age range is estimated on the basis of sediment accumulation rates from ~0.3 to 0.5 cm per year (SIEGEL *et al.*, 1993; LOIZEAU and STANLEY, 1994). For this study, 13 samples were examined in the short cores collected in former Abu Qir lagoon (Figures 2B and 11C), a water body converted to agricultural land during the last century. In these samples special attention was paid to abundance of the four key species that help distinguish specific modern lagoon biofacies and also shed light on environmental conditions in this former lagoon.

Sufficient shell material was available for identification and counts in 10 of the 13 core samples examined; two samples contained microfossils but no molluscs, and one was devoid of any fauna. Fewer taxa were present per volume of sediment than in surficial samples of modern Nile delta lagoons. The eighteen species recorded in Abu Qir cores are among those listed in Table 1. Proportions of species (especially *H. stagnorum, A. ovata, C. glaucum* and *P. conicus*) were calculated, as were the proportions of fresh water, lagoon *s.s.* and marine taxa (data available from the authors).

Biofacies A, B (including variant B*) and C were identified (Figure 12, upper). In addition, one strand-plain (comprising primarily near-beach, open marine species, see Figure 11C) assemblage and one marsh (entirely fresh water) were noted. The molluscan biofacies of Abu Qir indicate somewhat more lagoon *s.s.* settings than those in modern Nile delta lagoons. Core AQ1 is the most diverse and displays, from the base upward, a change from lagoon *s.s.* to marine influenced. Core AQ2 reveals a change upward from marsh to fresh-water influenced lagoon. This in-

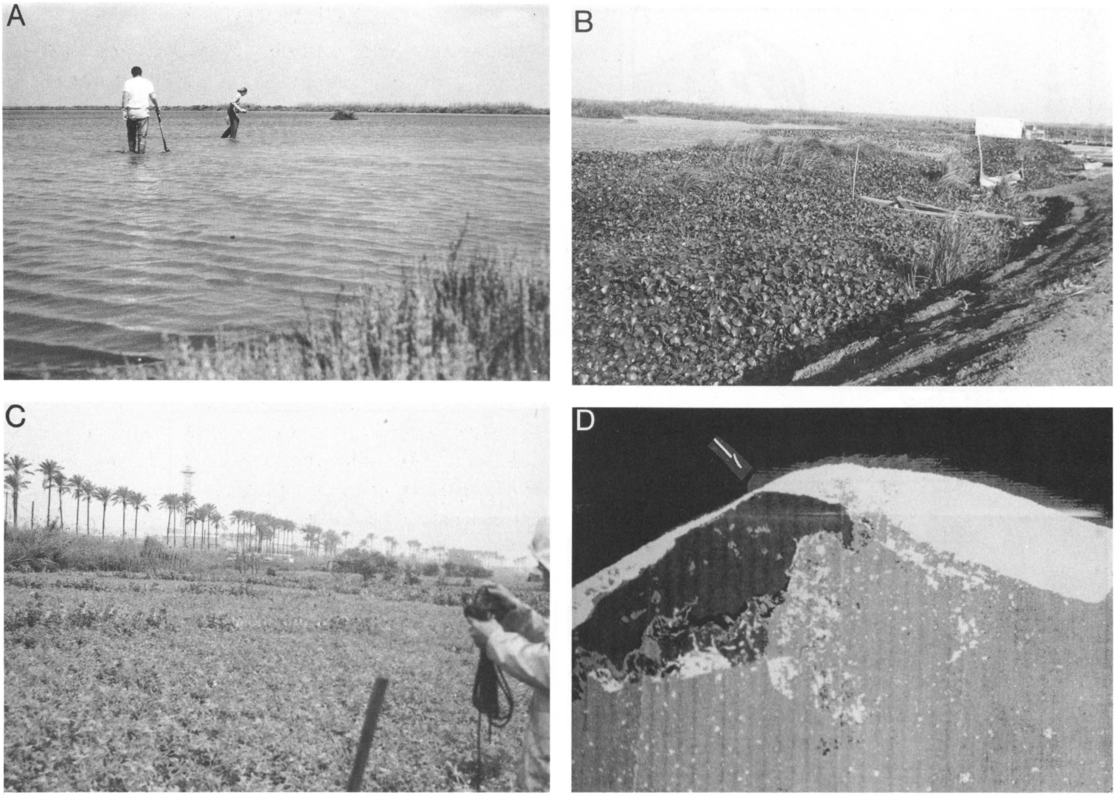

Figure 11. A, southern margin of Burullus lagoon transformed to a shallow fish pond; B, high mud ridge bordering south shore of Burullus lagoon, as a result of recent land reclamation project; note thick concentration of water hyacinths; C, former Abu Qir lagoon, at short core site AQ1 (palms in background are positioned on former sandy strand-plain deposits on southwest shore of Abu Qir Bay); D, satellite image (Landsat 1, 31 August 1972) showing outflow of sediment-enriched waters (arrow) from Burullus lagoon, through the outlet near El Burg, into the Mediterranean.

creased marine influence with time, not clearly recorded by petrologic subfacies analysis (LOIZEAU and STANLEY, 1993), likely records conditions associated with closure of the former shallow water body: increased salinity during its final evaporation phase in an arid setting.

Faunas in Holocene Sequences

The general results derived from our quantitative study of modern surficial lagoon samples were also applied, but in simplified manner, to the older Holocene subsurface record (past 7,000 years) in the Nile delta region. A qualitative consideration of relative abundances of the four key mollusc species, as well as of marine and freshwater faunas, was made in selected cores that comprise Holocene lagoon sequences. Rather than specific counts, a general frequency scale (abundant, present, rare, absent) was devised. An examination was made of 25 samples from three long Smithsonian cores, S-62 and S-72 recovered in the Idku lagoon area and S-74 in the former Abu Qir lagoon region (Figure 2B). These samples, collected at subsurface depths of ~2 to 9 m, were selected from deposits previously identified as lagoonal (CHEN *et al.*, 1992; WARNE and STANLEY, 1993; LOIZEAU and STANLEY, 1993). Seventeen of the 25 samples had shell material for evaluation (all are species listed in Table 1); two samples contained microfossils but no molluscs, and six were devoid of any fauna.

The four key species were observed in these long core sequences, and an evaluation of their general frequency and proportions reveals the presence of biofacies B, C and variant B* (Figure 12, lower) that characterize modern Nile delta

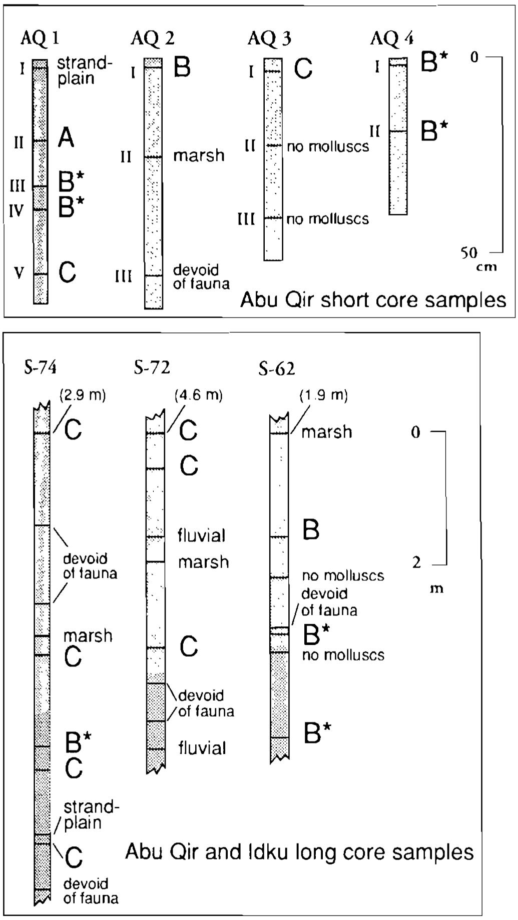

Figure 12. Logs of subsurface Holocene lagoon sequences, showing molluscan biofacies A, B and C, and variant B*, as defined in Figures 6 to 8. Upper, distribution in four short cores in former Abu Qir lagoon. Lower, faunal distribution in three long Smithsonian cores in the northern Nile delta.

lagoons. Also recorded are several samples with fluvial (essentially fresh water), marsh (fresh-water species associated with abundant plant debris), and strand-plain (worn shell fragments of shallow nearshore, open marine) taxa. Molluscan biofacies in these three long core sequences record somewhat more lagoon *s.s.* environments than do the modern Nile lagoons. The faunas, however, do not show any clear time-related or lateral trends, unlike up-core changes recorded in the Abu Qir cores. Rather, marked temporal and spatial biofacies variations record rapid paleogeographic and paleoclimatic fluctuations of the former lagoons (*cf.* STANLEY and WARNE, 1993).

COMPARISON WITH PETROLOGICAL OBSERVATIONS

Relatively large numbers of petrological subfacies have been defined in surficial sections of Idku and Manzala lagoons (RANDAZZO, 1992; LOIZEAU and STANLEY, 1993) and in Mariut lake (LOIZEAU and STANLEY, 1994). These are primarily a response to diverse physical and biogenic depositional processes that affect shallow water bodies in the Nile delta, even those of modest size. In the case of lagoons, these processes are mainly controlled by geomorphic setting; *i.e.*, limited access to the sea by a narrow inlet, seasonally strong wind influence resulting in vertical mixing of the shallow water column, and basins backed by marshes. The nature, origin and distribution of Idku and Manzala petrological subfacies are ultimately a function of the spatial configuration of fresh-water dominated (landward and along lagoon margins) to brackish (in lagoon basins proper) to higher salinity-dominated (near inlet) zones typical of lagoons receiving both fresh and marine water input.

The smaller number of molluscan biofacies and their more extensive geographic distribution in modern Nile delta lagoons, as compared to petrological ones, can be explained by several factors: larger size of the shell material, and wide tolerance of species to ecological conditions (euryhaline and eurytherm taxa). Mud and sand (63 to ~500 μm) fractions, which define most Nile delta petrological subfacies, are more easily displaced by bottom currents (particularly by wave reworking of the bottom in winter), than much coarser (> 1 mm) molluscan remains. This process-related phenomenon would explain the contrast between more diverse, size-sorted petrological subfacies as defined in Idku and Manzala lagoons (RANDAZZO, 1992; LOIZEAU and STANLEY, 1993) and Mariut lake (LOIZEAU and STANLEY, 1994), and smaller number of molluscan biofacies in these same water bodies as distinguished in the present study. Moreover, the geographic distribution patterns of molluscan biofacies and petrological subfacies need not be coincident. Life habit (such as burrowing in bottom sediment), and large size and weight would enable some taxa, such as *C. glaucum*, to withstand displacement by current transport, unlike the associated sand and finer fractions in which they live.

The role of sediment transport and lateral reworking should not be ruled out, however, in interpreting mollusc-rich deposits. X-radiographs of lagoon sequences in cores, for example, reveal stratified shell-rich horizons. Some strata comprise variable thickness (to > 30 cm) of autochthonous shell concentrations which accumulated *in-situ* (Figure 3A), while others are coquina-like layers of displaced valves (Figure 3B and C). Core sequences also reveal alternating layers of autochthonous and displaced shells (Figure 3B). It is thus likely that when stratification attributes of both autochthonous and allochthonous assemblages are considered, the number of molluscan biofacies in Nile delta lagoons is actually larger than recorded in our present study of surficial grab samples. Molluscan biofacies could perhaps be better defined on the basis of species abundances integrated with information on spatial distribution of shells in sediment and their associated structures, such as burrows.

This study indicates that, even with the still-limited information, molluscan assemblages provide environmental information not available from sediments alone. For example, the influence of marine water at and near inlets of Manzala and Idku lagoons is more clearly indicated by faunas (Figure 9; EL-WAKEEL and WAHBY, 1970: Figures 2 and 3) than by texture and sediment composition alone (EL-WAKEEL and WAHBY, 1970: Figures 4 and 5; LOIZEAU and STANLEY, 1993: Figure 10). In the case of older lagoon sequences, such as those recovered in cores, definition of molluscan assemblages also supplement petrological interpretations. Particularly valuable in this respect is recognition of short-term temporal fluctuations of salinity conditions.

Until recently, lagoons have accounted for the single most important and widespread environment in the northern Nile delta plain. Anthropogenic pressures, due largely to the extremely rapid growth in population, are now dramatically changing the configuration, conditions (salinity, pollution and other; SAAD *et al.*, 1985; KERAMBRUN, 1986; SIEGEL *et al.*, 1993) and uses of water bodies in the lower delta plain (STANLEY and WARNE, 1993). It is recommended that further evaluation of molluscan biocenoses, sensitive markers of environmental conditions, be made in studies of the rapidly altered Nile delta lagoons and Mariut lake.

SUMMARY

(1) Dark, plant- and shell-rich muds and sandy silts of lagoon origin are widespread in the northern Nile delta of Egypt, and these deposits are characterized by a larger proportion of molluscs than other deltaic facies. The present study defines modern molluscan assemblages and their distribution in surficial sediment of Idku, Burullus and Manzala lagoons and Mariut lake. This faunal examination was made to better interpret environmental attributes of these shallow water bodies, which are now undergoing very rapid change as a result of accelerated anthropogenic activity.

(2) Faunal examination was made of 78 samples, including surficial grabs in the four modern shallow water bodies, short cores collected in former Abu Qir lagoon, drained and converted to farmland in the last century, and deeper cores which recovered older Holocene subsurface lagoon sequences. Quantitative analysis is performed on thanatocoenoses comprising a total of 47 species. Taxa abundances are the basis for a principal component analysis to define molluscan biofacies.

(3) An autoecological investigation provides information on environmental setting, ecological meaning, life-habit and feeding type for the identified species. On the basis of all available information, it is possible to assign a fresh-water, lagoon *sensu stricto* or marine setting to each taxon. Relative cumulative dominance values of each of these three settings are calculated for assemblages in each sample, and these reveal considerable faunal variability within and between the four Nile delta water bodies.

(4) Two major factors derived from a principal component analysis refer to dominance of *Hydrobia stagnorum* and to that of fresh-water species. Statistical analysis serves to distinguish three molluscan lagoon biofacies: those revealing a marine influence; those of fresh-water influence (including a variant comprising an infaunal assemblage living in bottom sediments covered with minimal and scattered vegetation); and those of lagoon *s.s.* origin.

(5) Molluscan biofacies indicate that Manzala, in contrast to Idku and Burullus, is the most fresh-water influenced lagoon, and also records greatest incursion of marine waters via its outlet. Although Mariut is now an enclosed lake, molluscan faunas (mainly lagoon *s.s.*) are statistically comparable to those in the three Nile lagoons. Mariut biofacies likely record its history when, early in the last century, it was a lagoon connected to the Mediterranean Sea.

(6) Modern Nile delta molluscan biofacies

comprise a somewhat larger proportion of fresh-water species than in many other Mediterranean lagoons. This is largely a function of important River Nile water discharge and consequent relatively low salinity. Delta projects have considerably reduced the size of Nile delta lagoons, and this presently results in a proportionally higher fresh-water input in these water bodies.

(7) Findings of the present study can be applied to the fossil record, including short cores from former Abu Qir lagoon dating back to about 200 years ago. Molluscan biofacies indicate somewhat more lagoon *s.s.* settings than those in modern Nile delta lagoons. This likely records increased salinity associated with closure of that former shallow water body, and its final evaporation phase in an arid setting.

(8) As a test, the method was also applied in a simplified manner to older (past 7,000 years), Holocene subsurface sequences in long cores recovered in the northern delta plain. General frequencies and proportions of taxa record somewhat more lagoon *s.s.* environments than in modern lagoons. The rapid spatial and temporal biofacies fluctuations in cores are a function of marked paleogeographic and paleoclimatic changes affecting former delta lagoons.

(9) The smaller number of molluscan biofacies and their more extensive geographic distribution in modern Nile delta lagoons, as compared to petrological subfacies, is a function of sediment transport-related phenomena. It is likely that the number of molluscan biofacies would be larger than recorded in the present study if both autochthonous and allochthonous (including coquina-like shell concentrates) assemblages are considered.

(10) Molluscan assemblages are sensitive markers of environmental conditions, such as fluctuations of salinity conditions, and thus supplement petrological interpretations. It is predicted, for example, that fresh-water influenced biofacies will become progressively more widespread as lagoons receive relatively substantial fresh-water input but continue to decrease in size. In view of the much-increased anthropogenic pressures, it is recommended that molluscan faunas be monitored in baseline studies of Nile delta lagoons and Mariut lake.

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