THE INTRODUCED ASIATIC CLAM, *CORBICULA*, IN CENTRAL ARIZONA RESERVOIRS

John N. Rinne
Research Associate
Department of Zoology and Lower Colorado River
Basin Research Laboratory
Arizona State University
Tempe, Arizona 85281

ABSTRACT

Horizontal and vertical densities and biomasses of Corbicula *in two central Arizona reservoirs were estimated employing meter square quadrats and Ekman dredge sampling. Concentrations of clams increased with depth of water and down-lake from inflow areas characterized by greater turbidity (suspended sediment,). Densities were highest on rock-rubble slopes and increased directly with complexity (number of components) of substrate. Data suggest food supply, substrate, turbidity and perhaps fish predation as important factors in determining densities and biomasses of clams in the two reservoirs examined.*

INTRODUCTION

Corbicula was first recorded in Arizona in 1956 from the Phoenix canal system (Dundee and Dundee, 1958). Introduction into Arizona, possibly from California, most likely occurred by man in the role of tourist, fisherman, or aquarium hobbyist. It was first recorded in abundance in the Southwest from the Coachella Valley, California, in 1953 (Ingram, 1959). In 1963, *Corbicula* had re-invaded irrigation systems of the Colorado River Indian Reservation after its eradication a year earlier (Ingram, *et al.,* 1964). Since that time it has spread throughout the entire lower Colorado River basin. The rapid spread of this animal upon introduction at various localities in the United States led Sinclair (1971) to describe *Corbicula manilensis* as " . . . currently the most costly liability of all exotic molluscs in North America . . ." This "pest" currently inhabits the Salt River reservoir system, central Arizona, where it occurs most abundantly in Roosevelt and Apache lakes (Fig. 1) *Corbicula* are scarce in the lower two reservoirs, Canyon and Saguaro lakes, for which I have no explanation since they are abundant upstream, and downstream in the Salt River between Stewart Mountain and Granite Reef dams and in the Phoenix canal systems. Locally, they comprise a major component of the benthic fauna of the upper two reservoirs.

Current Address: EAFFRO, P. 0. Box 1881, Kisumu, Kenya

METHODS AND MATERIALS

Corbicula were collected sporadically from

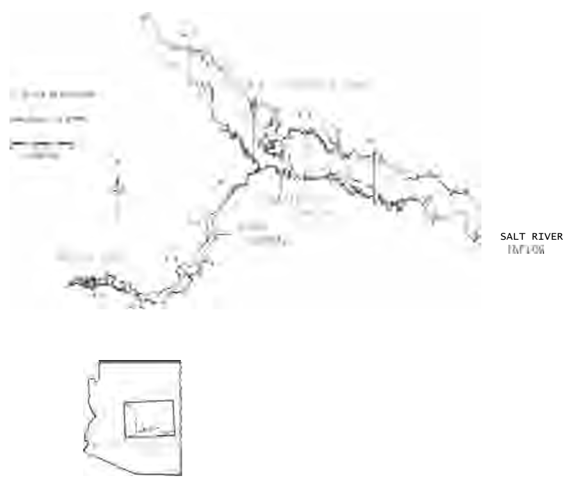

FIG. 1. The two most upstream lakes, Roosevelt and Apache, of the Salt River system of reservoirs showing transect locations and place names used in text.

Roosevelt and Apache lakes (Fig. 1) in November 1970, 1971 and February 1972. Almost all specimens were collected in a moribund state, or dead, on exposed lake shore during low-water conditions. Several meter-square (m2) quadrats were randomly thrown at a given site. All clams within this area with hinges yet attached were collected, and retained for later examination. In some cases intact valves would break upon handling, or were parted when later examined and measured. In either instance, these were counted. No specific information concerning time required to sufficiently decompose hinges and promote separation of valves was available to me. This undoubtedly varies with conditions following death. Most collections were made after a drop in reservoir level and consisted predominantly of individuals which had died of desiccation. Time-lapse between collection and exposure to drying varied in all cases, and could, indeed, affect density estimates. Autumn 1970 collections in Roosevelt and Apache were both within a month after the substrate was exposed by receding water. The November 1971 sampling in Roosevelt at R-1 was performed near water line and specimens were most likely exposed for only 2 to 3 months. By contrast, November 1971 and February 1972 collections in Apache were subject to approximately 7- to 10-month exposures, respectively, and sampling across from Frazier's Landing (equidistant between R-2 and R-3, *see* Table 2, Fig. 1) was undertaken on bottom that had been dry for more than a year. Other shortcomings of such collecting techniques were alteration of information by predatory mammals and birds, and activities of man. The last was circumvented to a large extent by selecting sites away from human activities.

Clams were measured (widths) and counted in the laboratory. Live clams were processed to determine dry and ash-free dry weights of animals excluding the valves. Regression analysis of size and weight indicated a power function giving the highest r-value (+0.98; equation: $y = [0.0110608] \times X^{3.0129}$). Mean size of all *Corbicula* within a quadrat was employed to estimate approximate biomass per unit area using the plotted regression line.

RESULTS

Two, shallow-to-deep-water transects at arbitrarily selected locations in Roosevelt and Apache lakes were sampled to determine the possible effect of depth of water on densities, sizes, and biomasses of *Corbicula.* Both transects generally indicated an increase in numbers and biomasses of clams with progression to deeper water (Table 1; Fig. 1), depending somewhat on substrate. Sampling in approximately 3.4 meters (m) of water on the north shore of Roosevelt Lake yielded no clams on rubble bottom. At deeper, downslope sites, the animal became progressively more dense. Substrate along this transect was generally rocky. However, diversity of the habitat, increased directly with increasing depth. Shallower sites were far more uniform in sizes of substrate components, whereas at deeper levels, sand, rubble, gravel and boulders were interspersed. Average sizes of clams neither consistently, nor significantly, changed with depth.

The transect near A-2 (Burnt Corral, see Figs. 1 and 2) was located on an extremely steep, rock-covered slope, with the exception of several m^2 quadrats sampled on mud-sand flats. Numbers of clams were low at a depth of 2.2 m on sand-silt substrate (Table 1). Quadrats at 3.4 m were located near the crest of a rock slope (approximately 26% grade). Numbers and biomasses of clams then increased dramatically, remaining high to a depth of 18 m, where a drastic decrease in density occurred. The last site (BC-1-5) was located at the base of the rocky slope and was composed of sand-gravel substrate. Four quadrats were sampled on sand-gravel substrate, lying upon the old river terrace immediately below the rocky slope. Numbers also were extremely low in this area (BC-4-1). Several more quadrats were sampled at 20 and 22 m below full lake level (BC-2-1 and BC-3-1), on a second rocky slope, which dropped toward the old river channel. Densities of clams increased over those on the

TABLE 1. AVERAGE SIZES, DENSITIES, AND BIOMASSES OF CORBICULA AT SHALLOW-TO-DEEP-WATER TRANSECTS IN ROOSEVELT AND APACHE LAKES. RANGES ARE SHOWN IN ( ).

TRANSECT DESCRIPTION	DEPTH BELOW FULL POOL WATER MARK (M)	SUBSTRATE	AVERAGE SIZE (mm)	NUMBER/M^2	BIOMASS KG/HA
APACHE LAKE (BURNT CORRAL)					
BC-1-1	2.2	Sand-silt	19.6(7-38)	7.0(5-9)	6.0
BC-1-2	3.4	Rubble	19.7(5-37)	208.0(27-367)	181.0
BC-1-3	9.0	Rubble	22.5(3-38)	383.0(221-589)	482.6
BC-1-4	13.4	Rubble	19.8(3-38)	380.0(240-499)	338.2
BC-1-5	18.0	Gravel-sand, small rubble	22.5(10-38)	25.0(20-29)	31.5
BC-4-1	17.0	Sand-gravel	25.0(19-28)	3.0(5-9)	5.4
BC-3-1	22.0	Rubble	14.5(8-20)	32.0(0-64)	9.9
BC-2-1	20.0	Sand-rubble	18.4(7-20)	17.0(0-34)	12.2
ROOSEVELT LAKE (NORTH SHORE EQUIDISTANT BETWEEN R-2 AND R-3)					
F-50	3.4	Rubble	0.0	0.0	**0.0**
F-100	7.0	Rubble	13.8(5-25)	22.0(12.3)	6.6
F-150	10.4	Sand-gravel	20.2(8-36)	124.0(86-166)	117.8
F-200	14.0	Sand,gravel, rubble, boulder	19.2(8-32)	176.0(121-163)	140.8

higher terrace, however, they were far lower than those on the shallower, rocky slope. Mud flats near this locality, despite excavation to depths of 0.5 m yielded no indications of clams.

Another shallow-to-deep transect similar to those discussed above was sampled in the vicinity of R-4 (Fig. 1) on a predominantly silt slope containing little rock or sand. Eleven m quadrats were examined - seven contained no clams, three had 2, and one had 3 clams. Two quadrats at approximately 15 m below high waterline contained only 2 clams/m. Two samples from about 17 m of water contained only 2 and 3 clams/m. These data also support the evidence for greater densities in deeper water and on rock-rubble slopes.

Variation in average sizes, numbers, and weights per unit area of all Corbicula collected in areas as near to established transects as possible in Roosevelt and Apache lakes are in Table 2. No consistent trends in average sizes of clams were detectable among localities in Roosevelt Lake. Greater biomass, however, was present at down-lake transects (e.g. R-2). Densities of clams at about a kilometer (km) east of R-2 and on the north shore of Roosevelt roughly equidistant between R-2 and R-3, were 2 to 6 times the mean densities, and 4 to 10 times the biomasses recorded nearer inflow areas. Evident harvesting of clams by humans at Frazier's landing, a major boat launching area, was reflected in drastically lower densities (Table 2). Considering all quadrats sampled in

TABLE 2. AVERAGE SIZES, NUMBERS, AND BIOMASSES OF CORBICULA AT SELECTED LOCALITIES IN ROOSEVELT AND APACHE LAKES. RANGES ARE SHOWN IN ( ).

LAKE LOCALITY	AVERAGE SIZE (mm)	NUMBER/M^2	B1CMASS (KO/HA
ROOSEVELT			
R-1	[illegible]	53.0(12.0-103.0)	10.0(1.4-14.0)
1 km. E. R-2	14.3(12.0-18.3)	119.0(42.0-241.0)	43.0(10.7-87.5)
Frazier's Landing	21.8(18.8-27.8)	19.0(52.0-243.0)	110.0(10.6-137.8)
N. shore of Roosevelt equidistant from R-2 and R-3	18.3(14.2-20.9)	110.0(32.0-243.0)	110.0(10.6-137.8)
APACHE			
A-2	25.9(23.5-29.0)	26.0(11.0-59.0)	49.9(35.9-105.6)
0.5 km. N. A-2	20.6(10.6-27.9)	177.4(5.0-588.0)	194.7(0.65-1,060.0)
A-3	20.8(17.2-25.9)	73.0(14.0-166.0)	68.9(18.2-164.3)
A-5	18.4(11.5-21.8)	65.0(30.0-192.0	56.2(11.4-214.0)

Roosevelt Lake, numbers of clams ranged from 12 to 243/m , and biomasses from 1.4 to 137.8 kilogram per hectare (kg/ha).

Average size, density, and biomass of clams generally decreased downlake in Apache (Table 2). Great variation in these parameters at two sites, one at A-2 and another less than a km north, reflects the influence of bottom type on clam populations (Table 2). At A-2, the substrate consisted of compacted gravel, and clams were scarce; however, in boulder-strewn slopes, up-lake Corbicula were almost eight times as numerous per unit area (Table 2). Furthermore, three sets of adjacent samples taken in February 1972 on rock-boulder (in contrast to the sand-gravel substrate at A-3 in Apache Lake— (Fig. 3) yielded significantly greater densities in all cases in the former, ranging from 2.5 to 9.0 times higher (66-25, 121-14, 38-8) than in A-3's sand-gravel substrate type.

Over-all, densities of Corbicula in Apache Lake ranged from 5.0 to almost 600/m , and standing crops from 0.65 to 1,060 kg/ha, excluding weights of shell. Analysis of variance showed non-significant differences between numbers, sizes, and biomasses relative to depth at all transects and in comparison of samples from the two localities at A-2.

Meager data on Corbicula were obtained from Ekman dredge samples (Table 3). Few clams occupied the soft, fine-grained sediments that the Ekman dredge sampled most efficiently. Numbers of live clams taken in Ekman dredge samplings were comparable to those collected in meter square quadrats. For example, 5 of 20 Ekman samples taken at A-2, in Apache Lake indicated clam densities of 43 to 86/m (Table 3), compared to 26/m estimated by the quadrat method (Table 2). Densities of clams at A-5 estimated by these same two sampling methods, also were comparable (Tables 2 and 3).

DISCUSSION

Data from Roosevelt and Apache Lakes were not significantly different at the 0.05 level in either biomasses or numbers of clams between lakes or in most cases, among

TABLE 3. SUMMARY OF CORBICULA COLLECTED WITH AN EKMAN DREDGE IN APACHE LAKE, 1971.

TRANSECT, STATION	DATE	NUMBER CONTAINING CORBICULA	NUMBER/DREDGING	ESTIMATED NUMBER/M^2
APACHE				
A-2-I	3-30-71	3 of 8 dredgings		43.0
A-2-II	3-29-71	1 of 10 dredgings	2	86.0
A-2-III	3-30-71	1 of 2 dredgings	2	86.0
A-3-I	3-23-71	1 of 8 dredgings	4	172.0
A-4-I	3-22-71	2 of 10 dredgings		43.0
			2	86.0
A-5-I	3-22-71	3 of 15 dredgings	2	86.0
				43.0

transects, but actual values of each of these seemed to vary inversely up- to down-lake, when the two reservoirs were compared. Inflow areas of Roosevelt Lake were more turbid, and normally had more phyto-plankton as indicated by chlorophyll-a data (Portz, 1973; Rinne, 1973). As given above, clams were far more dense down-lake from inflow areas in Roosevelt Lake. The effect of greater inorganic suspended solids at the Salt River inflow of Roosevelt may well have suppressed the population of clams, despite an adequate food supply.

By comparison, densities and biomasses of *Corbicula* decreased down-lake in Apache Lake in presence of both sparser food and less turbidity relative to that recorded in up-lake sectors. These data indicate that food supply may be more limiting to *Corbicula* than turbidity. Prokopovich (1969) recorded de-creases in densities of clams downstream in the Delta-Mendota Canal, California, and attributed this to decreasing food supply. However, turbidity as a factor in affecting dispersion of clams can not be eliminated as indicated by my data and that of others. A high mortality of *Corbicula* in the Ohio River in spring was attributed to increased tur-bidities (more than 400mg/1) by Bickel (1966).

Vertically, densities of *Corbicula* seemed to increase with depth, modified somewhat by bottom type and location within the reservoir system. This may be an indication of the influence of food supply (phytoplankton) as effected by photic conditions (Portz, 1973; Rinne, 1973). In addition, rocks and boulders upon slopes within these two reservoirs provide protection for juvenile clams from predators. Several species of fishes; carp *(Cyprinus carpio* Linnaeus), smallmouth *(Icti-obus bubalus* [Rafinesque]) and black *(Icti-obus niger* [Rafinesque]) buffalofishes consume large numbers of *Corbicula* (Minckley, *et al.,* 1970; Rinne, 1973). Increase in densities of clams with depth may therefore be a reflection of greater fish predation in shallower areas of the lake.

Corbicula is known to remove suspended organic and inorganic particles from water and deposit them as pseudofeces (Proko-povich, 1969). Heinsohn (1958) reported two to three small *Corbicula* were capable of clearing 500 milliters of "very turbid water" in less than 2 minutes. Precipitation of plankton from aquatic media by *Corbicula* was reported by Greer (1971), and laboratory studies at Arizona State University suggested filtration rates are directly related to concen-tration of algal cells in solution (Richard

Stephenson, pers. comm.). Above certain critical concentrations of algal cells, clams began indiscriminantly to precipitate food and inorganic particles, presumably to clear their gills and thereby prevent asphyxiation.

Ideal conditions for *Corbicula* seemingly would include both clear waters and adequate food supply. Large concentrations of this clam downstream from hydro-electric dams has been attributed to clear, plankton-rich waters (Heard, 1964). I noted the greatest concentrations of clams (1,500/m), in the canal below Granite Reef Dam where both clear water and adequate food were present.

FIG. 2. Photograph of a rock-rubble slope typical of central Arizona reservoirs (A) and closeups (B and C) showing complexity of these habitats and interstices providing protection for clams from fish predation.

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