A REVIEW OF INTERACTIONS BETWEEN HUMANS AND FRESHWATER MUSSELS IN TEXAS

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ABSTRACT. Human exploitation of freshwater mussels has occurred since prehistoric times. Prehistoric utilization was minor, but mussels were used as food, ornaments and tools. Historic utilization has involved food, button manufacture, pearls and "seed" for cultured pearls. Human impact has also occurred because of water projects and water pollution. Legal regulations, outlook for the future and environmental significance of freshwater clams are discussed.

The freshwater clams of the family Uniondae in Texas remain an imperfectly-known fauna. Following early compilations by Singley (1892, 1893), the only comprehensive treatment has been Strecker (1931). However, a plethora of nomenclatorial uncertainties and modern development of the biological species concept have combined to limit the usefulness of Strecker's monograph.

Delineation of species limits in unionids is difficult due to a complex interaction between natural genetic variation and external environmental factors which result in phenotypically plastic taxa. Consequently, a survey of the unionids of Texas and contiguous drainages is presently underway. Preliminary studies have revealed a moderately diverse fauna of approximately fifty species with centers of diversity in eastern and central Texas. The fauna consists of species derived from Mexican rivers and the Mississippi drainage in addition to several autochthonous forms (for details on the zoogeographic patterns of unionids in Texas, see Neck, 1982 in this volume).

Significant populational impacts have occurred even before the native fauna has been characterized. The purpose of this communication is to review the effect of human activities upon the freshwater naiads of Texas. Reference will be made in particular to Texas populations, but pertinent examples will be drawn from elsewhere.

DIRECT HUMAN IMPACT. Direct human impact includes those human activities which directly influence freshwater clams. Such activities are generally limited to utilization of naiads for food, tools or ornaments.

Prehistoric Utilization. Utilization of unionids by prehistoric culture groups (Baker, 1929; Matteson, 1953; Morrison, 1942) is well documented in the eastern United States, including Texas. Primary exploitation undoubtedly involved human consumption, but certain characteristics of freshwater clams limit their utility as a foodstuff. A low level of nutrients in clam tissue and low dry-weight per individual clam generally preclude the dependence of even a moderate-sized settlement on naiads as a major food source (Parmalee and Klippel, 1974). Most species are commonly found concentrated in mussel beds which may be highly localized and scattered. Yet, the existence of large deposits of clam shells in archeological sites (Meighan et al., 1958) indicates a general (i.e. widespread) utilization of clams as a periodic food source (Forrester, 1964; Murray, 1982).

A small fraction of clam shells from archeological sites exhibit one or more modifications as either ornaments or tools (Jackson, 1938). Shells believed to be oranaments often have one or more simple holes which appear to have been carefully drilled (Lord, 1978; Neck, in press). Such shells probably function as necklaces, breastplates or other ornamentations.

Modified clam shells from archeological sites often may be interpreted as tools because the modification appears to be non-ornamental. Utilization of the putative tool may be difficult to determine unless ethnographic data are available. Clams appear to have been modified to form digging instruments, food implements or containers (Jelks, 1962; Sayles, 1935).

Historic Utilization. Historic direct utilization of freshwater clams appears to have been mainly as food and ornamentation with only local use as tools. Freshwater clams have never been widely accepted as a foodstuff in the United States. Conversations with persons who have sampled various species report the meat to be "rather chewy" with little flavor variability between species (D. J. Bereza, pers. comm.). Chowder recipes are preferred by most people (Bigony, 1979). Essentially the entire animal is edible although certain organs associated with the alimentary tract are likely to have a strong taste. Often, only the larger muscle masses are consumed. Unconfirmed reports have indicated utilization by restaurants of freshwater clams as food items (under another, certainly more appetizing name).

As a foodstuff today, freshwater clams are probably more widely utilized as fish bait or pet food. Much of the clam meat which is accumulated by the cultured pearl industry (see below) is sold for pet food or fertilizer. The Asiatic clam, Corbicula fluminea, has colonized most of North America during the last 40-50 years. The major method of inter-drainage dispersal is probably as potential fish bait; unutilized clams are often discarded.

Freshwater clam shells or products made from shells have been widely utilized in an ornamental manner during historical times (Smith, 1919). Primary utilization of shell material by Americans was as buttons. Thousands of pounds of shell were removed from American rivers during the latter half of the nineteenth century and the first half of the twentieth century. Indeed, essentially all of our early studies or ecology, growth and zoogeography of freshwater clams resulted from commerically -oriented studies by the U.S. Bureau of Fisheries. Utilization of buttons made from mother-of-pearl of freshwater mussels in Texas was concentrated in the Lower Rio Grande Valley (Garrett, 1929). Exploitation often concentrated on several species with strong thick shells in each area. The only species utilized in the Valley was *Cyrtonaias tampicoensis*.

In kind with their marine relations, freshwater clams also produce pearls in response to irritants (see Kunz, 1897). A thriving pearl industry developed around Caddo Lake in the early twentieth century (Shira, 1913). An estimated $100,000 worth of pearls was removed from Caddo Lake in 1912, a year considered poor in comparison with previous years. Interestingly, the shell resource of the Caddo Lake area was not utilized by the button industry because of transportation costs and competitive high local wages ($3 per day in oil fields). Fine white pearls were obtained from *Megalonaias gigantea* and *Tritogonia verrucosa* while colored pearls were found in *Plectomerus dombeyanus*; pearl color is the same as the nacre color for a particular individual.

Freshwater pearls are of minor significance in our modern economy, but are occasionally publicized (e.g. Mannix, 1965). However, there is one stream in Texas which still produces significant amounts of pearls. Individuals of *Cyrtonaias tampicoensis* in the Concho River in the vicinity of San Angelo, Tom Green Co., produce high-quality pearls of a purplish color. A local jeweler purchases 500 to 1200 of these pearls each summer on an *ad libitum* basis from local residents, primarily adolescents. Most pearls vary from 3 to 8 mm in diameter; the largest known is 13 mm in diameter (Pinkard, 1979).

While freshwater clams no longer provide large amounts of pearls, these animals are still a part of the modern pearl industry. Thousands of pounds of freshwater clam shells are annually exported to Japan for use in the cultured pearl industry (Lopinot, 1967). Pearl culture began in 1912 when Kokichi Mikimoto developed successful methods in Japan. Various potential nuclei, i.e. irritants, were tested. The best nuclei were those made from freshwater clam shells. Primary locations of diverse, high-density populations of freshwater clams in the world are eastern North America (especially the Mississippi River sytem) and mainland China. For some years China has had essentially no trade with Japan because of political factors; therefore, the Japanese cultured pearl industry has depended entirely upon shell from the United States (Lopinot, 1967).

Fuller (1974:251) has listed the major impacts of collecting for the cultured pearl industry as follows: 1) reduction of brood stock to a level that reproduction may not equal mortality; 2) physical alteration of substrate of mussel bed areas; 3) stress-induced abortion of brooded young following disturbance at improper times for successful reproduction; 4) "waste deaths" of juveniles below legal and/or utilitarian limits; and 5) uprooting of adults which are often not able to rebury themselves correctly. Fuller (1974:251) considers the use of diving gear to be "the greatest threat to commercially valuable mussels today."

The total tonnage of clam shell removed from the waters of Texas is unknown, although the figures must be large. Reports of shell removed from various reservoirs in Texas by a single company are given in Table 1 (a total of 3,820,252 pounds during 1978-1981). Shell operations by other companies are occurring in other drainages and reservoirs. Preferred species in Texas are Amblema plicata, Quadrula apiculata and Proptera purpurata. During the drought of 1978 many Texas reservoirs were at record low levels, allowing easy access to numerous clams by "amateur" shell collectors who sold their booty to shell companies for 20 cents per pound. Enterprising persons hired several children to dive and collect clam shells. One such person accumulated over 1100 pounds on his most successful day of operation. The shell industry in Texas has reached the economic point such that one company is considering some form of clam cultivation in order to increase and ensure a quantity of shell for their customers. Such methods have been successful elsewhere (Jones, 1950).

Although the lag time between shell collection and purchase report by the shell company is unknown, certain patterns of harvesting are evident (Table 1). Most harvesting occurs during the warm season. Harvesting peaks are evident in drought years (1978 and 1980) with much less activity in wet years when the reservoirs are full (1979) or flooding (1981). Harvesting activities have been concentrated in Eagle Mountain Lake (Tarrant Co.) and Lake Lewisville (Denton Co.) in the Trinity River drainage. Minor amounts have been removed from Lake Brownwood (Brown Co.) and Cedar Creek Reservoir (Henderson and Kaufman Counties).

Table 1. Reported clam shell harvest from various Texas reservoirs by a single shell company (pounds).

	1978	1979	1980	1981
January	-0-	24,400	85,800	88,000
February	-0-	-0-	44,000	44,000
March	80,400	-0-	156,200	84,000
April	69,200	87,800	174,00	70,600
May	111,600	66,874	214,400	57,525
June	220,800	68,253	381,400	-0-
July	188,400	30,000	188,400	-0-
August	232,800	89,200	198,600	-0-
September	295,000	52,800	44,000	-0-
October	99,000	73,400	-0-	14,000
November	40,000	67,800	-0-	-0-
December	40,800	36,600	-0-	-0-
Total	1,378,200	597,127	1,486,800	358,125

To prepare a nucleus for a cultured pearl, the thickest portion of the clam shell is cut into strips and then cubes which are then ground and polished into a spherical shape. These pellets are then sold to pearl farmers who insert the pellet into an incision in the foot of three-year old Japanese pearl oysters. The oysters are then placed in submerged wire cages for an average of three years. Pearls are then removed, graded, sorted and polished.

Freshwater clams are also utilized to a minor extent in art crafts. Some of the larger shell shops in coastal Texas sell freshwater clam shells as well as the more colorful and more popular marine mollusc shells. Some of the naiad shells found in shell shops in south Texas are imported from Mexico. Shell waste from the cultured pearl industry can be manufactured into craft products (Mathiak, 1974).

Mollusk shells in general and clam shells in particular have long been a symbol of life, apparently because they represent an organism even after its death (Saul, 1974). In small central Texas towns with a dominant central or eastern European cultural influence, gravesites are occasionally covered with clam shells placed directly on setting mortar. Usually the shell involved is a marine species (the giant Atlantic cockle, Dinocardium robustum seems to be most common). However, an occasional grave is covered with freshwater clams.

INDIRECT HUMAN IMPACT. Certain human activities do not involve exploitation of freshwater clams but nevertheless affect individuals and populations of certain species. Included are activities which involve habitat modification (impoundments, channelization, runoff pattern alterations, water pollution and aggregate removal) and faunal modification (fish stocking, inter-drainage water transfers and clam transfers).

Habitat Modification. Probably the most significant human activity to influence freshwater clams involves the numerous impoundments which have been constructed on most major and many minor streams. Construction of an impoundment has two major effects on the clam population. There is an increase in the absolute area of suitable habitat. Clams originally restricted to favorable areas of a narrow stream are able to colonize large areas of shallow water. In many cases, the original stream bed becomes unsuitable for freshwater clams because of accumulation of soft silt, development of an anoxic zone and the increase in water depth.

The most obvious effect of impoundments upon these clams is a change in species diversity, because those species adapted to lotic waters are unable to reproduce under reservoir conditions. Loss of species in reservoirs has been attributed to changes in water temperature and chemistry which alter reproductive success and survival rates (Isom, 1971; Cvancara and Freeman, 1978).

Certain species, however, are able to flourish under such conditions and become extremely abundant, e.g. Amblema plicata and Quadrula apiculata. Murray (1972, 1979) has reported on the unionid fauna of Lake LBJ and Lake Corpus Christi. Important in the ability of A. plicata to survive in impoundments is the ability to survive in water with no dissolved oxygen for 10 weeks (Imlay, 1971).

Streams which naturally support only a few species of clams may exhibit an increase in species number following impoundment. Lake Texoma was created on the Red River in 1944; prior to that time only four mussels were known from that section of the river although sixteen species existed above the dam site in various tributaries (Isely, 1925; Valentine and Stansbery, 1971). Subsequent observations of the naiad fauna of Lake Texoma (Sublette, 1954; Riggs and Webb, 1956; Valentine and Stansbery, 1971; White and White, 1977) have revealed a fauna of 13 species in the reservoir. While some of the increase is undoubtedly due to an increase in survey area, species enrichment may result from a maturation of clam microhabitats through time (White and White, 1977).

The clam community may be transformed from a many-species community to a community dominated by one to several very common species. Original clam communities in the Elm Fork of the Trinity River contained 17 species (Strecker, 1931; Read and Oliver, 1953; Read, 1954). An unpublished survey of Lake Lewisville has revealed the presence of 13 species (Neck, in prep.); this total includes two native species which normally are found in ponded water. These two species, *Anodonta grandis* and *Anodonta imbecillis*, have apparently become more common since the construction of various impoundments. Both of these species are rare or absent in shell middens of archeological sites in areas where they are now common (Murray, 1982). Species no longer present include those more adapted to moving water than those which remain. Species reduction due to impoundment is much greater in areas which are characterized by high-gradient, clear rivers, e.g., streams of the Tennessee River. Several species have become nearly extinct due to impoundment of these streams (Bates, 1962; Isom, 1969; Stansbery, 1971). Decline of species diversity can often be verified by comparison of living faunas with prehistoric shell middens (White, 1977; Parmalee *et al.*, 1980).

Several clam species adapted to lentic water have been able to colonize small lakes, i.e. stock tanks, in areas which previously had only intermittent streams with no native unionid fauna. Survey of 15 small ponds on a tract of land near Athens, Texas (Henderson/Van Zandt counties) revealed unionid populations in nine ponds (Neck, unpub.). *Uniomerus tetralasmus*, *Carunculina parva*, *Ligumia subrostrata*, and *Anodonta imbecillis* were present in 7, 6, 4 and 2 ponds, respectively. The only pond which contained all four species also had the lowest elevation and was more susceptible to flooding with input of fish with glochidia.

Other habitat modifications which conceivably have affected freshwater clam communities exist. Channelization of streams includes an initial construction impact which reduces or eliminates populations and habitat. Such channels are not inherently inferior habitats if the walls and floor are stable (Wilson and Clark, 1912).

However, the resultant rapid runoff (instead of a slower, less variable discharge) with alternating periods of desiccation precludes recolonization by most, if not all species. Widespread land clearing, urban development and groundwater withdrawal (Brune, 1975; Muller and Price, 1979) all tend to exacerbate the problem rapidly changing water levels and velocities. Increased rates of soil erosion have exacerbated the problem of silt accumulation (Ellis, 1936). Removal of aggregate, i.e. sand or gravel, may impact mussel beds by killing individuals and removing required substrate which may or may not be replaced by subsequent fluvial activities.

Water pollution caused by excessive amounts of municipal, agricultural and industrial wastes has a general effect of reducing diversity of most natural benthic communities. Clam communities are likewise affected (Fuller, 1974). The earliest report of pollution effects on freshwater clams was reported by Shira (1913:6) who reported that saltwater and waste from oil and gas wells in the Caddo Lake area destroyed "many fishes and mussels." A noticeable decline in unionid population levels has been reported in the *resacas* east ("downstream") of Brownsville, Cameron Co., in the 1950's (B. T. Warburton, pers. comm.). Although utilization of DDT increased during this time period, the casual factors appear to be non-point source urban pollutants. Healthy populations of unionids presently occur in the area west ("upstream") of Brownsville.

A study in the San Marcos River revealed that freshwater clams are adversely affected by sewage effluent (Horne and McIntosh, 1979). Critical water parameters did not differ above and below point of outfall but clams were less abundant below the point than above. Apparently, critical stress levels occur during periods of low water flow. Oxygen depletion below 20% saturation level (which may occur as a result of sewage enrichment) has been shown to be a major stressor of freshwater clams (Ellis, 1937; Ingram, 1957).

Faunal Modification. Faunal modification is an apparently minor impact resulting from uncommon circumstances. Fish stocking activities are an everyday occurrence in our society. While it is possible for fish with attached glochidia to be involved, indication of such clam transfer requires that the new locality be beyond the normal range of the clam (Johnson, 1970). Two episodes have been demonstrated in Texas (Metcalf and Smartt, 1972; Neck, 1982); undoubtedly, numerous others occur. Existence of clams in stock tanks on drainages with no native unionid fauna is almost always due to fish stocking activities. However, there is the occasional interested person who deliberately places freshwater clams in a new stock tank.

An Asiatic clam, *Corbicula fluminea*, has colonized essentially all waterways of North America (Britton, 1979) including Texas (Britton and Murphy, 1977) following its initial Texas report in El Paso (Metcalf, 1966). This clam has planktonic larvae with no dependence upon fish. These life history characteristics (Aldredige and McMahon, 1978) plus a tolerance for polluted waters (Habel, 1970) have resulted in population explosions which have paralleled recent declines in unionid populations. A cause-effect relationship has not been established and research on this topic is quite limited (Boozer and Mirkes, 1979). The concurrent decrease of native pleuroceriid snails and increase in the European snail, *Bithynia tentaculata*, in New York has been shown to be due to modified competitive relationships intensified by lake eutrophication (Harman and Forney, 1970). No such relationship involving native unionids and *Corbicula* has yet been demonstrated.

In addition to possible impacts on native fauna, *Corbicula* is a major problem in fouling condenser tubes of water-cooled electric generators (McMahon, 1977). Utilization of *Corbicula* in integrated biological treatment of wastewater (Dinges, 1976) has been proposed but initial trials have been unsuccessful. Interestingly, the imminently successful *Corbicula* is the only known introduced freshwater clam in North America (Hanna, 1966; Dundee, 1974).

THE FUTURE. With continued economic development and population growth in Texas during the next few decades, human impact on clams will continue. Additional impoundments are planned; the only factor which cancels an impoundment project is high land values due to urban development. Such development brings its own impacts. Hopefully, pollution control and monitoring will progress to the point that freshwater clams may be able to recolonize areas which are presently unsuitable for survival. Plans for inter-basin transfer of water present the possibility of colonization by species not native to the recipient stream.

Acid rain (which includes both acidic precipitation and atmospheric deposition of acidic particles) has become a major environmental concern during the past decade (see Babich *et al.*, 1980; Cowling and Linthurst, 1981; Harnbeck, 1981). Naturally "pure" rainwater has a pH of about 5.7 due to dissolution of atmospheric carbon dioxide. However, a modern industrial civilization based upon fossil fuels produces oxides of sulfur and nitrogen to such an extent that rain pH values are significantly reduced. General environmental effects of this phenomenon are still unclear but aquatic organisms in acidic streams with low buffering abilities are known to suffer reproductive depression or even significant increase in mortality rates. Freshwater clams may be affected either directly or indirectly due to decimation of teleost communities. In Texas, effects of acid rain are likely to be most obvious in the eastern portion of the state due to the location of lignite deposits and stagnating wind patterns (Arena, 1981). Unfortunately, this area is characterized by acidic streams which drain soils with low buffering abilities.

LEGAL REGULATIONS. Like most of the so-called "lower animals," freshwater clams are not subject to the vast array of statutory regulations which affect vertebrates. Collecting of freshwater clam shells is, however, regulated by the State (Parks and Wildlife Code, Chapter 8, Subchapter A). Originating during the time of exploitation of mussel shell by pearl and button industries, this regulation requires a license (fee is $10.00) of anyone who "...may take any mussels, clams, or naiads or their shells from the public water of the state...". Each person collecting clams is required to have a permit; no permit is required for any person or company who only buys the shell material. No statement of amount of shell collected is required. Prior to 1978 only a very few permits were issued (Table 2). At that time a Tennessee shell company began to buy shell in Texas. Note that permit numbers were highest during the drought years of 1978 and 1980. The peak in 1980 may have been partially influenced by increased publicity (Bigony, 1979; Pinkard, 1979).

Table 2. Number of mussel shell permits issued by Texas Parks and Wildlife Department by fiscal year (FY63 = September 1962 to August 1963).

FY63	1	FY69	3	FY76	0
FY64	1	FY70	7	FY77	0
FY65	1	FY71	0	FY78	205
FY66	0	FY72	0	FY79	111
FY67	2	FY73	0	FY80	520
FY68	4	FY74	0	FY81	115
		FY75	0		

Utilization of river aggregate is regulated by the Texas Parks and Wildlife Department. Concern is centered around siltation of the downstream riverine environment and destruction of teleost breeding grounds. Such concern will also tend to protect clam beds which may be concentrated in such areas (in part because the host fish are concentrated in these habitats).

At present several freshwater clams are listed as Endangered or Threatened by the U.S. Fish and Wildlife Service. None of the currently listed species occurs in Texas (Chambers, 1982). A list of restricted and declining nonmarine molluscs of Texas (Neck, ms.) includes a number of clams. Several of these species should be considered for listing by the USFWS, e.g. Lampsilis satura, Proptera amphichaena and Popenaias popei. All three of these species are naturally restricted to limited areas of Texas. L. satura and P. amphichaena appear to be quite limited as they are known from eastern Texas and western Louisiana. P. popei is also known from northeastern Mexico. All three species have been affected to some degree by human activities. Lack of precise data on these species precludes an accurate judgment of the status of these species in Texas at this time.

WHY CARE ABOUT CLAMS? The logical counter-argument to concern about freshwater clam communities is to ask, "What good are they?" Certainly the economic value is not significant when compared to the Gross National Product, but the extra income earned by the clam collectors is certainly significant to their families. Additionally, those persons wishing to possess pearls may do so with less economic investment due to the development of the cultured pearl industry.

The real importance of freshwater clams (even if not accepted by the general populace) is the part they play in a functioning ecosystem. These clams are filter feeders, taking in both suspended sediment and organic materials. The shells provide substrate for many aquatic insects which in turn are fed upon by numerous aquatic and terrestrial organisms (some of which are economically important to fishing and hunting interests). Clams provide food for fish and waterbirds in addition to such economically important furbearers as raccoon and muskrat. Utilization of various phyto- and zooplankton species as food (by the clams) may provide a significant regulatory dampening effect which benefits other aquatic life, including fish.

Research is now appearing in the literature indicating that clams can be a important bioassay of past and present benthic conditions. *Amblema plicata* has been used to monitor trace metal contamination due to mine tailings or industrial pollution (Manly and George, 1977; Adams *et al.*, 1981; Gardner *et al.*, 1981). Monitoring of pesticide levels in aquatic environments by utilizing freshwater mussels has been reported (Bedford *et al.*, 1968).

Additionally, clams are of cultural enrichment value in that the term clam has taken on new meanings in our fluid language. The term "clams" is used as a slang equivalent to U.S dollars while a reticent or taciturn person is known as a "clam." In addition, the term "clammed-up" refers to a person who will not talk about a certain topic. A hinged dredging bucket is known as a "clamshell." Also, clams are used, albeit only occasionally, in our humor (which has important social functions). The most widely known utilization is in a widely syndicated comic strip -- the walking clam (with anatomically incorrect legs) of "B.C."

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