An Assessment of the Biological Characteristics, Abundance, and Potential Yield of the Queen Conch (*Strombus gigas* L.) Fishery on the Pedro Bank Off Jamaica

by

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ABSTRACT

An assessment of the queen conch fishery in the area of the Pedro Bank, Jamaica was conducted during 1993 and 1994 to assist in the proper management of the stock. Various data on morphometrics, population structure, growth, density and overall abundance were gathered to examine possible limitations of habitat on the population as well as to make estimates of potential yield which could be sustainably harvested. Morphometric data revealed that conch were in general larger and heavier at a shallow (6 m) protected site with extensive seagrass beds than at a deep (18 m) barren sand site with sparse algal cover. Adult conch categorized by shell erosion (normal, stoned, severely stoned) were significantly different ($P<0.05$) in shell length, lip thickness, and total weight. Population structure was skewed toward adult conch (> 79%) over the majority of the Bank. A large proportion of the adults were "stoned" with signs of extensive bioerosion indicating ages in excess of 12 years. Density estimates from 58 sites ranged from 88.6 to 276.6 conch/ha increasing with depth and distance from exploited areas. Total abundance was estimated at approximately 150 million individuals. Maximum sustainable yield estimates (MSY) ranged from 834 to 1800 MT annually the greater of which is a result of the large standing stock of older conch. It is felt that the deep (mean=24.5 m), barren nature of the majority of habitat on Pedro Bank reduces the occurrence and success of recruitment events. The present level of harvest (>2000MT) is not thought to be sustainable beyond 10 years at best.

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1.0 INTRODUCTION

1.1 General Biology and Ecology

The queen conch, *Strombus gigas* Linnaeus, 1758, is a large marine gastropod mollusk of the order Mesogastropoda. It is one of seven species of the family Strombidae (strombids or conchs) in the Western Atlantic. Its geographic distribution extends from Bermuda and southern Florida throughout the southern Caribbean and into northern coast of South America (Clench and Abbott 1941) but is not found south of the Orinoco River in eastern Venezuela. Generally the shell is tan on the outside and pink or yellow inside. The eye stalks and proboscis are black and white. The large muscular foot bears a corneous operculum and the shell has large prominent spines. Shell morphology may vary greatly depending on environmental (diet, temperature, geographic location, etc.) and genetic variations. Number and size of spines as well as length to width ratios of the shell have been known to vary (Alcolado 1976, Ray and Stoner 1995)

Queen conch (pronounced "konk") are also known as pink conch, pink-lip conch (Randall 1964) lambi, caracol or broad-leaf conch. In some regions very old conch, with thick, heavily eroded shells and leathery, black skin, are called samba, sanga (Randall 1964) or stone conchs. The term "Stoned" is derived from Jamaican fishermen who refer to "stone conch" as those conch whose meats are more difficult to chop out due to their thick shells.

Queen conch are found in clean waters, most commonly associated with sandflats, which support seagrasses and algal species where conch derive both food and shelter (Stoner and Waite 1990). Shelter is most important for the juvenile cohorts and the use of seagrass beds as nursery areas for queen conch is well known (Randall 1964; Weil and Laughlin 1984; Stoner and Waite 1990). Juveniles spend much of their first year (0+ cohort) of life as substrate infauna, occasionally feeding epibenthically at night (Randall 1964). Recent evidence suggests that conch remain buried continuously until they are approximately 50 mm in length and are very rarely encountered on exposed bottom before 90 mm in length (Iversen et al. 1989). Older juvenile and adult conch may also be found on gravel, coral rubble, and beach rock bottoms at increasing distances from the seagrass beds. Conch occur from shallow subtidal waters to 76 m, however their densities decrease significantly below 30 m due to light limitations for algal and plant growth (Randall 1964). Juvenile conch can often be found beached on sandflats or mangrove areas during low tide. Information on deeper populations of conch is limited due to accessibility (Berg 1981). Quantitative data on conch populations deeper than 6-8 m are relatively rare (Stoner and Sandt 1992). Such a deep water site (>18m), although shore-based for recruitment purposes, has recently been examined by Stoner and Sandt (1992) and was described as a refugium for deep water spawners. Berg (1975) observed that a 20 m deep algal plain off Puerto Rico was dominated by heavy shelled *Strombus costatus*, which was the most abundant large gastropod fauna, as well as specimens of *S. gigas*.

The importance of these deep water reproductive refugia to overall conch recruitment has been mentioned by other researchers including Wicklund et al. (1988) and Berg and Olsen (1989) however the critical nature of the relationship is not yet understood.

The queen conch is one of the largest herbivorous gastropods (Younge 1932). Conch are thought to feed primarily on macroscopic (e.g. *Laurencia* & *Batophora spp.*) and unicellular algae and the detritus associated with seagrasses (e.g. *Thalassia & Syringodium spp.*) and macrophytic algae (Robertson 1961; Stoner 1989; Stoner and Waite 1991a). Minimal consumption of living macrophytes was observed as component of diet during experiments by Stoner (1989). When conch live in largely sand substrate habitats large quantities of sand are ingested to obtain the unicellular algae and detritus associated with substratum (Robertson, 1961). The ingestion of small benthic animals is probably incidental during ingestion of considerable sand while foraging (Randall 1964). Conch feed both day and night but early juvenile conch (0+ cohort, < 90 mm shell length) are thought to feed at night and remain buried during the day (Brownell and Stevely 1981). Randall (1964) found that the dominant plants of a particular habitat are the dominant food for conchs. In laboratory experiments Creswell (1984) found conch to be selective in their diets with juveniles preferring filamentous algae and adults various red algae. Food preferences seem to change during the year, perhaps due to seasonal availability (Berg 1981). Food resources and depth of water significantly affect growth of conch (Alcolado 1976). Increases in conch densities and biomass correlated closely with increases in seagrass and detritus biomass and shoot densities (Stoner and Waite 1990). Low growth and high mortality were found among juvenile conch at sites of zero (sand site) or low seagrass biomass probably as a result of low food and inadequate shelter (Stoner and Sandt 1991b). In contrast it has been shown that conch grow more slowly at high densities of individuals even with unlimited food (Siddall 1984). More energy is expended while interacting with other individuals than is used for growth.

Reproductive activity occurs throughout most of the year (February to November) (Berg and Olsen 1989) but is at its greatest intensity during the warmer months (April to September) (Randall 1964; D'Asaro 1965; Brownell 1977; Buckland 1989; Stoner et al. 1992). The exact peak of reproductive activity will vary among particular locations within the region but seems to coincide with peak water temperatures. The sexes are separate and the sex ratio is generally accepted as 1:1 in nonbreeding aggregations (Randall 1964; Blakesley 1977), however, this ratio may vary at particular locations (Berg 1981). Breeding aggregations have been identified in some areas where very large individuals dominate and produce large masses of viable eggs (Berg et al. 1992). Sexual dimorphism exists, with females approximately 5% larger in shell length and 21% heavier at an age of 3.0 years (Appeldoorn 1986). Fertilization is internal. The penis (verge) is extended through the siphonal canal and up into the female genital (groove) region under the protection of the flared lip of the shell (Berg 1975). Males firmly attach their foot to the top back portion of the female's flared lip while engaged in copulation (Tewfik, in prep). The female can store sperm for subsequent spawning over several months (Berg 1981). Spawning occurs 2 to 3 weeks after copulation usually on clean coral sand with low organic content (D'Asaro 1965). The spawn (egg mass) is extruded as a sticky tube containing the eggs that is folded back and forth onto itself to which sand grains adhere (Randall 1964). Females produce an average of 8 egg masses a season (Davis and Hesse 1983), Each egg mass averages 300 000 eggs with as many as 750 000 being produced at any one spawning (Randall 1964, Buckland 1989).

The eggs hatch as planktonic veliger larvae approximately 5 days after spawning and feed on small phytoplankton (Robertson 1959; D'Asaro 1965). In two to three weeks, if conditions are right, veligers investigate the bottom but continue to feed planktonically (pediveliger stage; Brownell 1977). Metamorphosis is complete 4 to 5 weeks after hatching with the development of a proboscis, the disappearance of the velar lobes, and the beginning of a truly benthic lifestyle (Brownell 1977).

The growth of queen conch has been investigated at several locations throughout the Caribbean (Berg 1976, Alcolado 1976, Brownell 1977, Wood and Olsen 1983, Gibson et al. 1983, Iversen et al., 1987, Appeldoorn 1990, Rathier and Battaglya 1994). Estimates of mean shell length (tip of spire to distal end of siphonal canal) range from 66 mm to 121 mm for 1+ year old cohort, 125 mm to

185 mm for 2+ year old cohort), and 155 mm to 224 mm for the 3+ year old cohort. Typically juveniles under one year (0+ cohort, < 90 mm) are rarely encountered (Randall 1964, Hesse 1979, Inversen et al. 1989) and are usually undersampled (Appeldoorn 1987). Growth rate for shell length ranges from 1.8 mm/month (60 microns/day) to 6.0 mm/month (200 microns/day) depending on age, season, food availability and geographic location. Growth in shell length ceases once the shell lip begins to flare and thicken at an age between 3 and 4+ years (Alcolado 1976, Berg 1976, Wefer and Killingley 1980, Inversen et al. 1987, Appeldoorn 1988a, Buckland 1989). This period of change in shell growth may be termed sub-adult and refers to those individuals which have begun the flaring of the lip but most likely are not sexually mature (lip thickness of 1.0 to 4.0 mm). There is a period when shell length and lip growth occur simultaneously (Appeldoorn 1994b). Age of lipped (adult) conch has been estimated by the measurement of lip thickness (Hesse 1976, Wood & Olsen 1983, Appeldoorn 1988a) and estimate a conch with a 20 mm lip to be approximately 5 years old. However, radio isotope analysis aged a 12 mm thick lip conch at 7 years (Wefer and Killingley 1980). As bioerosion reduces the thickness of the shell on the outer surfaces the inner surface (aperature) have shell material laid down. This results in the volume of the shell being reduced as the animal ages (Randall 1964). Age estimates using lip thickness need to be critically assessed.

Sexual maturity occurs between 5 and 10 months from the initial onset of shell lip growth (Appeldoorn 1988b; Buckland 1989). The age of first reproduction appears to coincide with a lip thickness of about 4.0 mm (Egan 1985; Appeldoorn 1988a; Buckland 1989). Age of first reproduction has been estimated between 3.0 to 4.0 years (Berg 1976; Hesse 1976; Blakesley 1977; Egan 1985, Appeldoorn 1988b; Buckland 1989). Conversions of linear growth measurements into weight have been attempted and are most effective for juveniles (Randall 1964; Alcolado 1976; Berg 1976; Wood and Olsen 1983). This may be explained by the fact that when conch reach maturity a marked decrease in weight growth occurs (Appeldoorn 1994c).

Mean longevity has been estimated to be between 6 and 7 years (Berg 1976, Wefer and Killingley 1980), however, conch may live to over 15 years of age and individuals as old as 26 years are suspected (Coulston et al. 1987). Little work has been done on these old conch because relatively few are encountered and those that are found generally inhabit the deeper and more inaccessible habitats such as deep canyons, slopes and offshore banks where fishing activity is low or absent.

The overall rate of natural mortality in queen conch decreases until sexually maturity when it levels off (Appeldoorn 1988b). Values for instantaneous natural mortality (M) range from 2.12 for juveniles to 0.433 for adults (Appeldoorn 1988a, Rathier and Battaglya 1994) and subsequently estimates of mortality for the populationb as a whole are difficult to make.

Predation, the most important cause of juvenile (> 1 year old) mortality, is estimated at 60% annually (Iversen et al. 1986). Juveniles exhibit behavioural patterns to reduce predation by concentrating in shallow nursery areas, sometimes in large aggregations, away from large predators and remaining buried during the day for their first year of life. Long before *S. gigas* is mature, starting at shell lengths of 120 mm, juveniles are subject to harvest by the extensive commercial conch fishery. Adult conch suffer their highest rates of mortality (instantaneous fishing mortality,F =1.14, 0.68, 1.23) due to exploitation by man (Appeldoorn 1988a, Rathier and Battaglya 1995, Chevez, in prep).

The unique locomotion of *Strombus gigas* was first described by Parker (1922). First the posterior end of the foot is fixed by having the point of the operculum thrust into the substrate. This is followed by the extension of the foot anteriorly and the lifting and throwing of the shell forward in a sort of leaping motion, slightly akin to a pole vaulter. This motion tends to leave an unclear trail which may be a method of preventing or inhibiting predators from following the chemical trail of the conch (Berg 1975). Hesse (1980) has described *S. gigas* as a good climber of vertical cement surfaces. Most climbing occurs at night.

Hesse (1979) monitored the daily and seasonal movements and migrations of queen conch in the Turks and Caicos Islands. *Strombus gigas* exhibited " home ranges " which became increasingly larger with the age of the animal. Adults commonly movd 50 to 100 metres per day. Queen conch migrate seasonally, inshore during spring and offshore during fall (Hesse 1979; Weal and Laughlin 1984). The regularity of these migrations increased with age, possibly indicating movement for reproductive reasons. Recently movements by adult conch between sand bottom summer spawning grounds and mixed hard bottom feeding areas have been observed by Stoner and Sandt (1992). Mass migrations/aggregations of juvenile and early adult queen conch have been observed in the Bahamas with densities ranging from 20 to 300 individuals per m^2 (Stoner et al. 1988; Lipicus et al. 1992; Stoner and Ray 1993; Stoner and Lally 1994). The function of these migrations/aggregations is thought to be a mechanism of dispersal for recently emerged (1 + year class) animals and also to reduce predation.

The life history of conch provides for a period of larval dispersal (2 to 5 weeks) during which time larvae may be carried significant distances on ocean currents. Several recent studies (Berg et al. 1986; Mitton et al. 1989; Campton et al. 1992) have attempted to understand the patterns of larval dispersal and the genetic relationships within the geographic range of the queen conch. Spatial heterogeneity in allele frequencies exist among populations within island groups (Mitton et al. 1989). Certain populations (Bermuda) are almost totally isolated. In general, however, planktonic dispersal is believed to maintain high genetic similarity over broad geographic areas (Campton et al 1992).

A number of predators of *S. gigas* exist and have been reviewed in several papers (Randall 1964; Jory and Inversen 1983; Inversen et al. 1986; Coulston et al. 1987). Some predatory gastropods such as the tulip snail

(*Fasciolaria tulipa*), lamp shells (*Xancus angulatus*) and the horse conch (*Pleuraploca gigantea*) enter queen conch through the aperture to rasp the soft tissues. Various crab species and spiny lobster (*Panulirus argus*) peel the shell away whereas porcupinefish (*Diodon hystrix*), loggerhead turtles (*Caretta caretta*), spotted eagle rays (*Aetobatus narinari*), and hogfishes (*Lachnolaimus maximus*) simply crush the juvenile and young adult shell with strong mandibles and specialized teeth. The nurse shark (*Ginglymostoma cirratum*) has been filmed flipping large adult conch over to expose the aperture and then sucking the fleshy part of the animal out. Other predators include various grouper, snapper, and grunt species, tiger sharks (*Galeocerdo cuvieri*), queen triggerfish (*Batisles vetula*), and the common octopus (*Octopus vulgaris*). The breaking strength of the conch shell increases rapidly above shell lengths of 55mm and at larger sizes only certain predators can exploit them (Iversen et al. 1989). The most recent work on predation of juveniles (1+ year old, 90-109 mm s.l.) indicate that living in aggregations and attaining maximum overall size are the two most important mechanisms in escaping predation (Ray and Stoner, 1995). Differences in shell morphology (e.g. short vs. long spines) does not seem to provide particular advantages in preventing predation.

Commensals with queen conchs include conchfish (*Apogon steallatus*), porcelain crabs (*Porcellana sayana*), limpets (*Crepidula spp.*), and a variety of algae, sponges, hydroids, and bryozoans that foul the outer portion of the shell (Berg 1981). The diseases and parasites of *S. gigas* are poorly known (Berg

1981). Iversen et al. (1989) stated that parasites and diseases appear not to play a significant role in conch survival based on field observations. The boring activities of some sponges (Class: Demospongiae, Family: Clionidae) may be considered parasitic at times. These sponges are known to penetrate calcareous material, including oyster shells, and construct complex galleries within it. The boring activities inflict serious losses on the commercial oyster fisheries by making the shell (valves) fragile and are likely to shatter on opening (Bergquist 1978). Erosion of the shell due to excavations of *Clionidae* and other boring marine organisms seems to be a natural result of the aging process in older conch however its overall effect on the commercial fishery and conch meat yields has not been properly investigated.

1.2 The Queen Conch Fishery

Strombus gigas has long been valued for its delicious meat and beautiful shell and has been exploited since prehistoric times (Brownell et al. 1977; Berg and Olsen 1989). Initially queen conch were harvested for local consumption or limited inter-island trade (e.g. Turks & Caicos Is.) by artisinal fishermen. A sizable commercial fishery has only developed in the last 25 years as a result of the immigration of large numbers of Caribbean people to the United States (Brownell and Stevely 1981). The growing Caribbean population and increasing tourism also increased the demand for conch (Berg and Olsen 1989). Several authors have reviewed the conch fishery over the last two decades (Hesse and

Hesse 1977; Brownell and Stevely 1981; Stevely 1981; Gibson et al. 1983; Goodwin 1983; Berg 1987; Berg and Olsen 1989).

The former wide distribution and high abundance of conch has been severly affected by fishing pressure, due to ease of accessibility and harvest. The general impression is that conch stocks are now heavily overfished and depleted (Berg 1987). Once common in shallow waters, conch are now caught commercially at ever increasing depths (Berg and Olsen 1989). Fears of the disappearance of commercial conch fisheries by some biologists have caused *S. gigas* to be included on Appendix II of CITES (Convention in the Trade of Endangered Species). The overall dynamics of deep water, offshore populations of conch, which may be termed open systems for their non-shore based recruitment, have not been well studied even as their relevant contribution to the total biomass harvested has increased dramatically (Tewfik 1995). A recent estimate of overall conch harvest from the Caribbean region is over 4000 metric tonnes (MT) (Appeldoorn 1994a). This is based on reported landings used largely for export and does not reflect an unknown amount of local consumption and harvest as a result of poaching. An overall harvest using the most up-to-date figures put the total harvest at just under 6000 MT annually (Tewfik 1995).

As a result of dwindling stocks some nations have implemented management regulations and export restrictions to protect the remaining resources. These regulations include: closed fishing seasons, minimum size restrictions, daily catch quotas, closed areas and seasons, reservation of portions of stocks for local consumption, and the banning of certain fishing methods such as collection by SCUBA (Brownell and Olsen 1989). Despite regulations no examples of successful conch resource management exist (Siddall 1984). Most management plans have little, if any, biological basis due to a shortage of biological information.

The increasing economic importance of queen conch, as well as the reports of wild stock depletion, has sparked extensive work in the potential mariculture of conch (Berg 1976, Brownell 1977, Iversen 1983, Siddall 1983, Hensen 1983, Davis & Hesse 1983, Laughlin & Weil 1983, Ballantine and Appeldoorn 1983, Davis et al 1987, and Davis and Dalton 1992). These studies have demonstrated that *S. gigas* can be successfully raised using mariculture. Mariculture could possibly be used to seed commercially depleted areas or create sources of conch that are maintained in artificial settings using artificial feed until harvest. However the poor economic feasibility of such strategies due to prohibitive costs of feed and enclosures, combined with the limited information available about early conch life history make such options of limited use. There is an urgent need to manage and conserve the existing wild queen conch stocks rather than creating new ones that have a multitude of associated problems.

1.3 Pedro Bank

In Jamaica it was reported that a rapid expansion of the conch fishery was occurring on the south coast and banks of the island (Mahon, Kong, and

Aiken 1991). The increased catch appeared to be coming mainly from the Pedro Bank. The extent to which this bank is able to support heavy commercial conch fishing activity was in question due to the lack of biological data about the stock and physical nature of the habitat. Since the average depth of the bank is 24.5 m, much of which is flat sand plains (approximately 2/3 of the Bank) (Munro & Thompson 1973), it was thought that there may be limitations of suitable nursery (juvenile) habitat and overall food resources (Mahon, Kong & Aiken 1991). These limitations could seriously impact on the potential recruitment of conch into the fishery if the population was self-recruiting to a large extent. The overall supply of larvae avaliable to recruit to the benthic environment in Pedro is the net result of the internal production of larvae. It should be remembered that a portion of any internal larval production is potentially available to recruit to other areas in the region as larvae from other areas may recruit to Pedro. These regional larval movements and recruitment patterns are unknown but the isolated position of the Bank may limit any incoming larval drift. The deep, barren nature of the large sand plain areas of Pedro Bank may also provide poor habitat for those conch which do recruit to the benthos due to limits on seagrass, associated detritus, and macroalgae. Poor habitat could limit the potential conch biomass available to the commercial fishery on an annual basis.

The conch fishery on the south shelf and offshore banks to the south (Pedro and Morant Banks) had existed for decades but involved only artisinal fishers (Mahon, Kong, and Aiken 1991). During the early 1980's exploitation increased due to the establishment of collector/supply boat systems to the offshore cays (Pedro and Morant) where artisinal fishermen are based. The late 1980's represented the period of greatest expansion in conch exploitation and was the direct result of the entry of several commercial scale vessels (20 to 28 m) operating on Pedro Bank with as many as 20 divers using SCUBA and hookah gear (Mahon et al. 1993). The dramatic increase in conch exploitation seemed to coincide with a crash of the spiny lobster fishery in this region in the late 1980's. By early 1993 the commercial fleet consisted of at least 12 vessels which ranged in size from 17 to 55 m with as many as 60 divers per vessel (mean=22 divers/vessel) (personal observation 1993).

Jamaican Statistical Institute data indicated that 1500 and 2300 MT of conch were landed during 1990 and 1991 respectively on the basis of processed export values (Mahon et al. 1993). It was estimated that the potential sustainable yield of the Pedro Bank, based on estimates from other areas of the Caribbean, was approximately 600 - 800 MT per year (Mahon et al. 1993). It was therefore concluded that the current trend in exploitation would reduce the stock levels beyond the levels required for maximum sustainable yield (MSY) within one to two years (Mahon et al 1993). The lack of regulations for the conch fishery during its early period prevented immediate management from occurring. A worse case scenario of minimal self-recruitment, minimal incoming larval drift, and habitat limitations for spawning and recruitment could mean the elimination of commercial conch fishing for several decades on the Pedro bank if harvest levels were continued. With the potential loss of significant exports of conch meat ($ 9 million US. annually), local sales to the tourist industry, and livelihoods for artisinal fishermen, processing plant employees, and commercial fleet crew and divers in the near future, the need for current and accurate biological, ecological and fishery information was most urgent.

1.4 Purpose and Objectives

The overall purpose of this study was to gather biological, ecological and fisheries information to assist in the understanding and proper management of the queen conch stocks on the Pedro Bank. Previous to this study no data had been collected concerning this conch stock other than gross export value. These data would assist in determining a sustainable exploitation rate for the resource. The study addressed eight main objectives to fulfill the overall purpose. They were:

1. Description of the morphometrics within the stock
2. Description of the population structure
3. Estimates of growth rates and age using size frequency distribution
4. Estimates of population density and overall abundance
5. Estimates of potential yields
6. Effects and possible limitations of various habitat types on population structure, morphometrics, growth, densities, and potential yield
7. Description of the harvest sector and potential yield

8. Description of feasible management options and strategies based on data collected in previous objectives.

The purpose and objectives follow the goals of Jamaican Fisheries Division, Canadian International Development Agency which supported this research and CFRAMP (CARICOM (Caribbean community) Fisheries Resource Assessment and Management Program) which advocates " ... the promotion of management and conservation of fishery resources, to permit their exploitation on a sustainable basis," (Mahon et al. 1992). Also Mahon et al (1991), with input and support of Jamaican Fisheries Division, state that efforts should be made to update the biological information concerning the queen conch fishery on the south Jamaican banks.

Morphometrics were investigated by the measurement and comparison of various measures of the shell and soft parts of the conch and analyzed using functional regression techniques. Population structure was described from conch collected with regards to size/age class, sex, and erosion class . Estimates of growth were determined by size-frequency analysis. Population density and overall abundance were calculated from survey samples over a large area of the bank with the cooperation of industrial vessels and commercial divers in conjuction with Jamaican Fisheries officials. Estimates of potential yields of the stock were calculated from abundance survey data using both empirical and area based models. The effects and possible limitations of various habitat types on conch populations were examined by comparisons of population structure, morphometrics, growth, densities, and potential yield between three sites representing the three major habitat types as well as data on habitats observed at 58 sites during the abundance survey. Description of the harvest sector, potential yield, processing methods, and processing grades were determined with the use of vessel catch forms, diver interviews, collection of conch meat data directly at processing plants, and Jamaican Natural Resource Conservation Authority (NRCA) export data.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study area was on Pedro Bank, a large submarine plateau. The Bank lies south-west of Jamaica and is separated from mainland Jamaica by an approximately 70 km wide strait with depths exceeding 1000 metres , in the region between latitude 16°42'N and 17°39'N and longitude 77°19'W and 79°02'W (Fig. 1). Additional deep channels separate the Bank from other south-westerly shoals and banks. Pedro Bank, for depths less than 50 metres where the edge drops away rapidly, has an area of 8040 km^2, a maximum length of 168 km, a maximum width of 83 km in the west, a circumference of 590 km, and a mean depth 24.5 m (Munro and Thompson 1973). During this study I was only able to sample a small number of sites within the region of the bank shallower than 30 m in depth, which extended over an area of 6086 km^2. Mahon et al (1993) determined that commercial exploitation below 30 m was limited due to limitations of SCUBA diving and conch biology.

The Pedro Bank was surveyed by British Naval Hydrographic ships Fox and Fawn in 1970 and detailed charts for navigation are available (British Admiralty chart no. 260). The bank gradually deepens in a northwesterly direction and is shallowest in the southern and southeastern areas (Fig. 1). These shallow regions face into the Caribbean current and have well developed reefs. The ecological features of the bank are poorly known, including the extent of seagrass and algae cover, because of extremely limited scientific diving observations in the region. Diving conditions are difficult because of strong currents, rough seas, and abundant sharks (Munro and Thompson 1973).

The Bank has a mean sea surface temperature of 27°C with a seasonal variation of +/- 1°C, a tidal range of 0.33 m, and a mean salinity of 35 ppt which is presumed to be slightly higher in shallow water areas (Dolan 1972). Dolan (1972) made an extensive survey of the recent distribution of sediments on the Pedro Bank. Three distinct habitat types exist based on characteristic topography and sediment type; (**1**) Shallow reefs with irregular profiles that coincide with the shallowest areas, (**2**) Reef areas which have a more regular profile than shallow reefs and are characterized by sandy bottom with frequent isolated patch reefs, and (**3**) Sand blanket which composes two thirds of the bank and is made up of carbonate, biogenic, and sand detritus. For the purposes of this study the habitat types will be known as (**1**) Cay associated habitats (including seagrass beds and reefs), (**2**) Reef habitats, and (**3**) Sand plain habitats. The three sites used to represent the habitat types were SW Cay (SW) representing the Cay associated habitat, D-Shoals (DS) representing the reef habitat, and Juvenile Garden (JG) representing the sand plain habitat (Fig. 1, Table 1). The sites were some distance apart. SW Cay was 12.6 km from DS and 34.6 km from JG. D-Shoal was 23.8 km from JG. All three sites had experienced some level of fishing pressure in recent years based on evidence of "knocked" out shells on the bottom. All algae and seagrasses were identified to genus using Abbot and Dawson (1978). A large scale abundance survey permitted another 58 sites (Fig. 1) to be sampled once.

2.2 Data Collection

Three field periods (May to July, 1993, January to June 1994, and November 1994) were utilized to gather data on the Pedro Bank conch stock. During the first field period I familiarized myself with the present situation within the fishery including meetings with all the government, non-government, and commercial participants in the fishery. The logistics of the field work (research vessel, SCUBA tanks, divers, etc.) were organized, specific study sites on the bank selected, meat grade data collected and preliminary collections of conch in the field and analysis of data undertaken. The collection of meat grade data involved the weighing of individual meats given to us at a certain level of processing directly from arriving boats or in the plants. The grades were specified as 50%, 65%, 85%, or 100% clean referring to the amount of processing and tissue removal had that occurred to that point. Meats were generally given to us in a bulk container that was weighed and the weight of the container subtracted. From this I could determine the mean number of meats per kilogram at any particular grade. The "dirty" grade is not brought to the plant but is simply the total tissue of conch removed from the shell.

The second field period involved collection of the majority of the biological data pertaining to the three major sites (SW, DS, JG) on the bank used in the study (Fig. 1). Meat samples were collected in processing plants, as well as the collection of harvest sector effort and fleet data from both artisinal and commercial vessels. The third field period, in November 1994, was used to obtain density and overall abundance data at 58 sites over a large area of the Bank.

Seven day cruises aboard the Jamaican Fisheries vessel M/V Dolphin were conducted during the first two field periods to gather site specific (SW, DS, JG) data. M/V Dolphin is a 25 m double rigged Gulf trawler built in Texas in 1969 and sailed that same year to Jamaica . She has a top speed of 11 knots. Instrumentation includes radar, depth sounder, several two way communication systems and a Global Positioning system (GPS) allowing accurate location of sample sites. The vessel acts as an adequate dive platform and work area for the crew of 5 and up to 6 divers. A total of seven cruises (two during the first field period and five during the second field period) were made to complete the work. The third field period was staged from two commercial conch fishing vessels similar to the M/V Dolphin in most respects.

The three main collecting sites (SW, DS, JG) were located during the first field period to represent the three main benthic habitat types available to conch on the Bank. During the field periods dives with SCUBA were made at the three sites (SW,DS,JG) and conch were collected live by hand. The sites differed in water depth, substrate type, food resources, and their proximity to the artisinal landing sites at Pedro cays. The differences between the sites were thought to have a potential effect on the conch that metamorphosized, settled, and grew there. Not all sites were visited an equal number of times because of weather.

All conch were measured for shell length (LTH) and shell lip thickness (LIP) with the use of vernier calipers to the nearest 0.1 mm. Shell length is the measurement from the tip of the spire to the end of the siphonal canal and shell lip thickness is taken at the mid-lateral region on the lip side of the shell, 40 mm from the edge of the lip (Fig. 2). Shell lip thickness could only be taken from mature (adult) or maturing (sub-adult) individuals. Total weight, +/-5 grams, (TWT) was also measured for all conch, after epibiotic fouling was scrapped off, with the use of a triple beam balance. All remaining unlipped, juvenile conch were returned to the sea. Only fully lipped (> 4.0 mm) conch had shell weight (SHL) (empty), tissue weight (TISS) (meat & viscera), meat weight (MEAT) (50% clean, viscera removed), sex (M/F) and erosion level (N,S,SS) determined. Weight measurements are wet weights. A conch was removed from the shell by chopping a small hole in the fourth whorl of the spire and subsequently severing the columellar muscle attached to the central axis (Fig. 2). This is termed "knocking" the conch and is the standard method used by conch divers in harvesting the meats.

Erosion level is a fairly subjective assessment of an individual conch's shell and relative age. The erosion level categories for lipped conch refer to the overall wear due to boring and eroding marine organisms, movement over substrates, and general exposure to the marine environment over time.

Increasing erosion exhibits a general trend away from a stereotypical adult conch having prominent spines, generally smooth shell surface, and broad flared lip to an individual that has poorly defined spines, a pitted and sometimes crumbling outer shell surface, and lip which has lost the broad flared appearance but is very thick. The categories initially used during the second field period were Normal (N) describing a fully formed relatively thin lip with prominent spines and smooth outer surface, Stoned (S) describing a fairly thick lip, loss of the broad lip, with fairly worn spines and rough outer surface, and Severely Stoned (SS) describing very thick lip, very worn spines, and brittle outer surface (Fig. 3). The erosion level was used in an effort to age an individual adult conch using a method other than those described in the literature. During the third field period Stoned and Severely Stoned were combined leaving only Normal and Stoned categories.

2.3 Morphometric Data

The external form and structure were examined quantitatively using standard measures of the shell and soft parts for non-lipped and lipped conch (Randall 1964, Berg 1976, Wood and Olsen 1983, Appeldoorn 1987). The analysis of these data was used to determine possible population differences between specific sites (SW, DS, JG) as well as to determine relationships between measured structures. This would facilitate the estimation of a body parameter unavailable for examination from a parameter that was available. An example of this may be the estimation of an individual conch's shell length from a measure of the meat weight that would be available in a processing plant. General statistics (mean, standard deviation, range, etc.) were calculated for all measures of the shell and soft parts of all juvenile conch and the various categories including juvenile length classes, and adult sex and erosion categories. Morphometric relationships were established for each of the non-lipped size classes (Sm, Me, L), lipped erosion levels (N, S, SS) and sex (M/F). Standard regression techniques were used to develop correlations between the various body measurements. Total length (LTH) versus total weight (TWT) was the only relationship examined using non-lipped (juvenile) conch. Total length (LTH) versus total weight (TWT), shell weight (SHL), tissue weight (TISS), meat weight (MEAT) and lip thickness (LIP) vs. total weight (TWT), shell weight (SHL), tissue weight (TISS), and meat weight (MEAT) were examined for lipped individuals. All regressions and statistical tests were performed using Sigmaplot/Sigmastat statistical tools package for Windows version 2.01.

2.4 Population Structure

The population structure was examined in four ways: the percent frequency of non-lipped (N.L., juvenile) to lipped (Adult and sub-adult) conch, the sex ratio of lipped conch by the identification of male and female sexual structures, the percent frequency amongst juvenile categories, and the percent frequency of adults amongst erosion categories. Juveniles were categorized into three general length classes; Small (Sm, < 150 mm), Medium (Me, 151-200 mm), and Large (L, > 201 mm). Adult erosion categories are described in section 2.2 (N,S,SS). Chi-square tests were performed for each examination of population structure to reveal if any significant differences existed (eg. Lipped proportions between 3 major sites). Once significance was established z-tests were performed between individual pairs of observations (e.g. Lipped SW vs. Lipped DS). All statistical tests were performed using Sigmaplot/Sigmastat statistical tools package for Windows version 2.01.

2.5 Estimates of Growth and Age

The mathematical model for organic growth by von Bertalanffy (1938) has been used extensively in fisheries science to describe the growth of many fish, crustacean, and mollusk species, including *Strombus gigas* (Alcolado 1976, Berg 1976, Buckland 1989, Appeldoorn 1990, Rathier and Battaglya 1994). It is expressed as:

$$\mathbf{L_t = L_\infty \, [1\text{-}e^{-K(t-t_o)}]},$$

where $\mathbf{L_t}$ = length at age t; $\mathbf{L_\infty}$ = asymptotic maximum length; **K** = the growth coefficient; and $\mathbf{t_o}$ = the theoretical age when length was zero.

The von Bertalanffy (1938) model requires length at age data to make estimates of the growth parameters ($\mathbf{L_\infty}$, **K**, and $\mathbf{t_o}$). Size frequency analysis estimates age empirically from size measurements as conch have no hard structure (e.g. scales, otoliths, etc.) available from which to directly read ages. Mean growth is obtained from the differences in location of successive modal size groups (Appeldoorn 1988a). Size frequency analysis is a method of dividing a composite frequency distribution of a given measurement (e.g. shell length) into component normal distributions representing relative age/size, classes/cohorts (modal size groups) (Appeldoorn 1987). Measurement of size used can be any characteristic of an organism which increases with age. The use of size frequency data is particularly important in the tropical situations where seasonal variations are not clear and the spawning period is extensive.

Several methods exist with which to analyze size-frequency distributions for modal size groups. This study utilized the Bhattacharya method (1967), later modified by Pauly and Caddy (1985), in the form incorporated in the Modal Progression Analysis (MPA) sub-package of the "ELEFAN" (Electronic Length Frequency Analysis) length based fish stock assessment package (Gayanilo, et al. 1989). The details of the Bahattacharya method are given in Sparre, Ursin and Venema (1989). Essentially size-frequency data are transformed into points from which linear regressions, representing modal size groups, are separated. The mean values of modal size/age groups were used to calculate the parameters of the von Bertalanffy growth equation (1938), using the methods by Gulland-Holt (1959) and von Bertelanffy (Sparre et al. 1989). The determination of growth parameters through size-frequency analysis has been done previously for conch by Alcolado (1976), Berg (1976), Brownell et al

(1977), Wood and Olsen (1983), and Appeldoorn (1990). The problem of tightly overlapping modal size groups may be encountered especially in areas where spawning occurs throughout the year (Berg and Olsen 1989).

It is important when doing such analysis that the sampling is unbiased and representative of all modal size groups in the population (Appeldoorn 1988a). However, an undersampling of the infaunal portion of first year conch (0+ cohort) is unavoidable due to their secretive nature. Size-frequency analyses used shell length (mm) for non-lipped (juvenile) conch and shell lip thickness for lipped (adults & sub-adults) conch as the measurement of size changes with sexual maturation. The cessation of shell length growth at sexual maturity requires the use of lip thickness in adult conch (Wood and Olsen 1983, Appeldoorn 1988a). The rates of bioerosion and shell growth must both be known to accurately age adult conch using shell lip thickness. Appeldoorn (1988b) has criticized the lip-thickness frequency analysis method because a component normal distribution may represent several cohorts. Small sample sizes, single sampling events, have been criticized as limitations of lip frequency analyses done by Hesse(1976) and Wood and Olsen (1983) (Appeldoorn 1988b). Despite these criticisms a lip thickness frequency analysis was attempted in this study. Erosion levels (N, S, SS) were also used to establish relative age groups for adult conch because of the problems associated with lip frequency analyses.

2.6 Population Density and Abundance

For the purposes of this part of the study the Pedro Bank was divided into four zones defined primarily by management considerations (Fig. 1). The Artisinal zone (ART) comprised an area of approximately 37 000 ha and was represented by seven study sites. It is the region in closest proximity to the Pedro cays, includes all of the area of less than 10 m in depth as well as a small area of 10-20 m in depth, and represents the region that has the longest history of conch fishing on the bank. The second zone was the region of 10-20 m in depth outside the artisinal zone that represented the main region of activity for the commercial vessels. It comprised an area of approximately 201 700 ha and was represented by 40 study sites. The third zone was the region of 20-30 m in depth, was approximately 370 000 ha in area and was represented by 11 study sites. The fourth zone was the region deeper than 30 m and was not assessed due to the limits of safe diving and budget. The 58 sites assessed were chosen from a one minute latitude by one minute longitude grid placed over the bank. The X (latitude) and Y (longitude) coordinates were generated randomly by computer. The emphasis of the survey was to assess the area of primary importance to the commercial fleet (10-20 m zone).

The survey was conducted from two commercial vessels each responsible for surveying approximately 29 sites roughly divided into the eastern and western halves of the Bank. Each vessel had a group of commercial divers, research divers, and crew and were out for approximately 7 to 10 days. Study sites were located using a Global Positioning System. Once at a sampling site the mother vessel deployed four boats with a commercial diver and boat operator in each. The four boats would travel along transects at each of the cardinal compass points (N, S, E, W; Fig. 4). At 30 m from the mother vessel the commercial divers commenced sampling of sub-sites along the transect. Sampling involved collecting all conch within a sub-site and placing them into bags.

A sub-site was a circle with a radius of 7 m and a total area of 154 m^2. The commercial diver used a central weight with three ropes (7 m) each attached to the center to define the circle. Each commercial diver sampled 5 sub-sites along the transect (Fig. 4). Each sub-site was separated by approximately 20 m from outer edge to outer edge. The total area sampled at each site was 3080 m^2 (4 divers x 5 sub-sites x 154 m^2). The total area of the entire site was 70 685 m^2 which was defined by a circle approximately 150 m in radius from the mother vessels (Fig 4). Scientific divers deployed directly from the mother vessel insured that sampling methods were adhered to and also collected data on the habitat (substrate type, depth). Substrate types included sand plain (SP), algal plain (AP), seagrass meadow (SG), patch reef (PR), coral heads (CH), coral rubble (CR), hard bottom (H), and gorgonian/soft coral plain (GS) (Table 2).

All conch sampled by commercial divers were first defined as one of the six size/age categories: juvenile categories (Sm, M, L) if unlipped, as Sub-adult

(SA) if the lip was less than 4 mm, or as one of the erosion level categories (N, S) if assessed as an adult (Table 3). A proportion of sampled conch were also measured for shell length and shell lip thickness using vernier calipers to the nearest millimetre. Estimates of density were calculated per hectare (ha) by site for total conch and by each size/age category. Estimates of total abundance were also calculated for each zone for total conch and by size/age categories based on density estimates.

2.7 Estimates of Potential Yield (MSY)

The potential exploitable biomass was estimated from the number of normal and stoned adults estimated in the various zones during the November abundance survey and converted to mass using the mean number of conch meats in one kilogram of 50% clean meat obtained in the processing plants. These estimates in turn provided the basis for estimates of maximum sustainable yield (MSY) which were obtained through the use of empirical formulas and area based estimates.

The empirical formula defined by Gulland (1971) assumes that the stock is in a virgin state and that some estimate of overall biomass and natural mortality are available. The formula reads as follows:

$$\mathbf{MSY = X\ M\ B_V},$$

where **X** is a multiplier (0.5 being an average condition), **M** is the instantaneous natural mortality, and $\mathbf{B_V}$ is the virgin stock biomass. I argue that the 20-30 m zone of the Pedro Bank conch stock is in a virgin state due to the limited nature of the exploitation up to recent times. It is assumed that the X multiplier is 0.5 when fishing mortality (F) equals natural mortality (M) under optimum exploitation. Caddy and Csirke (1983) showed that this does not apply to many stocks especially prey species such as shrimp. It was concluded that MSY may be overestimated by 2 to 3 times using X = 0.5 and that the multiplier should be reduced to 0.2 (Beddington and Cooke 1983). Kirkwood et al. (1994) also found that the X multiplier ranged between 0.1-0.3. The natural mortality (M) rates calculated for queen conch over the life span range from 2.12 (juveniles, Appeldoorn 1988a) to 0.433 (normal adults, Rathier and Battaglya 1994). A natural mortality value of 0.3 was used emphasizing the suspected very low mortality (less than normal conch) and high abundance of stoned conch on the Bank. This is further supported by decreasing M values for conch over the exploited phase (Appeldoorn 1988b). The final state of Gulland's formula in this case reads:

$$\mathbf{MSY = 0.3*0.3*B_V}.$$

The second empirical method used was Cadima's (in Troadec 1977) that is designed for use in exploited fisheries (level of exploitation undefined) where limited assessment data is available. In the absence of total mortality (Z) data the formula reads:

$$\mathbf{MSY = X\ (Y + MBe)},$$

where **X** is a multiplier, **Y** is the total catch in a year, **M** is the natural mortality, and **Be** is the average exploitable biomass in the same year. In this case again X = 0.3 and M = 0.3 for reasons outlined in the Gulland formula. The Cadima formula was only used to calculate MSY for the ART and 10-20 m zones as they both had been under exploitation in the past. The value for Y was the 1994 estimate of exports which had come almost exclusively from the ART and 10-20 m zone of Pedro Bank. The final form of Cadima's formula reads:

$$\mathbf{MSY = 0.3\ (Y + 0.3Be)}$$

The values from the two empirical formulas (Gulland, 20-30 m and Cadima, ART + 10-20 m) were added together to give a single figure for MSY.

The first area-based estimate of MSY used the values of the most recent fully recruited year-class as a measure of productivity. Recruitment in this context refers to the cohort that will enter the harvestable portion of the stock. This assumed constant recruitment over time and was independent of the number of spawning adults. I thought that the combined number of large juveniles and sub-adults (3-4 year olds) formed the year class that was most recently recruited. The number in each zone was converted to mass by the 50% conversion factor resulting in the MSY estimate.

The final estimate of MSY used an area-based method and was compared to the Caicos Bank. The high productivity and stable nature of the Caicos Bank combined with the long history of data available made the Caicos Bank conch fishery a logical example for comparison. The overall estimated potential yield of the Caicos Bank for a given unit of area was applied to the area of the Pedro Bank. The use of three estimates of MSY for Pedro Bank was thought to provide a check for problems in any one of the various models.

2.8 Harvest Sector

The assessment of the harvest sector is often difficult in developing countries due to lack of centralized landing sites and available fisheries personnel. The analysis of the overall harvest sector consisted of two main components. First a description of the physical nature of the fleet (number of vessels, size, number of divers, gear, etc.) was made. This information was gathered from various Fisheries Department records, vessel catch forms , interviews with divers , and personal observations.

The second major component was a description of the actual harvest of the conch by the harvest sector. This consisted of export data by month and grade (process level) as well as detailed description of the grades and the conversion factors between grades. Export data was pieced together from NRCA records and grade and conversion information was obtained by random measurements of meats at local processing plants. Samples of individual meats were weighed using an electronic balance and sexed if possible (dependent on grade examined).

3.0 RESULTS

3.1 Morphometric Data

The shell length and total weight were measured for 1346 juvenile conch (SW = 966, DS = 36, JG = 344). The means (standard deviation, s.d) for juvenile shell length at SW, DS, and JG were 187(28.2), 186(28.9), 157(28.4) mm respectively (Table 4). The mean (s.d.) for juvenile total weight at SW, DS, and JG were 744(335.4), 696(352.9), 520(309.3) g respectively (Table 4). The juvenile categories (Sm, M, L) were also analyzed separately at each site in an effort to separate length classes within the juvenile population (Table 5). The mean (s.d.) shell lengths for Sm, M, L juveniles pooled from all three sites were 133.3(10.9), 177.8(14.3), and 214.9(10.8) respectively.

Analyses of variance (Kruskal-Wallis) was conducted for shell length and total weight and indicated that there were significant differences between sites ($P<0.0001$; Table 6). Specific comparisons (Dunn's method, all pairwise) between individuals at SW versus JG and DS versus JG showed a significant difference for both shell length and total weight ($P<0.05$; Table 6). In general SW juveniles were longer and heavier.

Correlations were established between shell length and total weight for all juveniles collected and all were significant at all three sites combined, ($r^2=0.897$; Fig. 5), all juveniles collected at SW ,($r^2=0.903$; Fig. 6), all juveniles collected at DS, ($r^2=0.839$; Fig. 7), and all juveniles collected at JG, ($r^2=0.904$; Fig. 8). Shell length-weight relationships for the length categories (Sm, M, L) at each site were also developed and indicated some good correlations (Table 7).

The mean (s.d.) shell length for all juveniles as a whole, and the three length categories (Sm, M, L), collected during the November abundance survey were 175.2(25.3), 131.7(14.9), 179.3(11.4), and 211.9(7.5) mm respectively (Table 8). These correspond well to the mean shell lengths for Sm, M, L juveniles from the three major sites (Table 5). Analysis of variance (Kruskal-Wallis) indicated significant differences (H=68.4, 2 d.f., P<0.0001) between all juvenile length categories (Dunn's, P<0.05).

A total of 773 adult conch were collected from the three sites (SW=210, DS=348, JG=215). The mean (s.d.) for shell length was 223.9(24.2), 193.9(22.3), 197.5(18.2) mm; for lip thickness 10.0(8.4), 20.4(6.2), 15.6(7.9) mm); for total weight 1634(357), 1498(342), 1393(294) g; for shell weight 1306(296), 1251(289), 1158(217) g; tissue weight 304(92), 260(81), 239(81) g; and for meat weight 182(53), 149(50), 136(47) g (Table 9). Analysis of variance (Kruskal-Wallis) was conducted among sites for each morphometric measurement and significant differences found between sites (P<0.0001; Table 10). Specific comparisons (Dunn's method) between individual sites indicated significant differences (P<0.05) among all morphometric measurements (Table 10). In general SW cay adults were longer and heavier in all respects except lip thickness.

A total of 346 of the adults were sexed (M/F) and LTH, TWT, LIP, and SHL were measured (Table 9). Rank sum tests (Mann-Whitney) conducted between the sexes at each site found that females were significantly longer in LTH and heavier in all weight measurements ($P<0.03$; Table 11). No significant difference was found between the LIP of males and females (Table 11). Analysis of variance (Kruskal-Wallis) revealed some significant differences ($P<0.05$) between conch of the same sex between sites (Table 12).

A total of 341 adult conch were categorized into size/age groups based on erosion level (N,S,SS) and LTH, LIP, and TWT were measured (Table 13). Analyses of variance (Kruskal-Wallis) were conducted among erosion levels for each morphometric measurement and were found to be significant ($P<0.001$). Individual comparisons (Dunn's method) between erosion levels indicated some significant differences (<0.05; Table 14). Normal conch were longer and heavier with thinner lips. Analysis of variance (Kruskal-Wallis) was also conducted between N conch between all three sites for LTH, LIP, and TWT. Significant differences ($P<0.05$) were found between all comparisons (Table 14). SW cay N conch were longer and heavier but had the lowest lip thickness.

Correlations between shell length and total weight for adults were found to be less significant than seen with juveniles at SW ($r^2=0.488$; Fig. 9), DS ($r^2=0.687$; Fig 10), and JG ($r^2=0.341$; Fig. 11). Shell lip thickness versus total weight relationships were also examined for adults and were not well correlated at SW ($r^2=0.022$; Fig. 12), DS ($r^2=0.030$; Fig. 13), and JG ($r^2=0.149$; Fig. 14).

Low correlations were expected due to changes in shell growth from length to lip and bioerosion. Shell length-weight relationships (Table 15) and shell lip-weight relationships (Table 16) for the all conch as well as by sex and erosion categories at each site were determined, with the strongest correlations occurring between individuals within narrow categories such as those conch of the same sex or individuals of the same erosion level.

The mean (s.d.) shell length for all sub-adults, normal, and stoned adults collected during the abundance survey were 207.5(19.1), 209.4(17.8), and 190.9(18.8) respectively (Table 8). The mean (s.d) shell lip thickness for normal and stoned adults collected during the abundance survey were 12.2(5.3) and 21.4(4.3) respectively (Table 8). Rank sum tests (Mann-Whitney) between shell lengths and lip thicknesses of N and S adults both indicated significant differences ($P<0.0001$) between categories with N conch having longer shells and thinner lips.

3.2 Population structure

The percent frequency of lipped (adult and sub-adult)(SW=210, DS=348, JG=215) to non-lipped (juvenile)(SW=966, DS=36, JG=344) conch indicated a significant difference between proportions of lipped and non-lipped conch (chi-square 3 x 2 ,site x lip presence contingency table, X^2=662.8, 2 d.f., $P< 0.0001$). Individual z-tests indicated a significant difference in the lipped proportions between all sites (P = 0.00). Lipped proportions of the populations are as follows: SW, 17.9% (z=17.0); DS, 90.6% (z=4.05); JG, 38.5% (z=13.5) (Fig. 15).

Sex ratio was analyzed using a chi-square 3 x 2 (site x sex) contingency table, (X^2= .27, 2 d.f.). No significant difference was found (P = 0.5309). The percentage of males at each site was 52.2% at SW, 56.6% at DS, and 49.4% at JG.

The percent frequency of non-lipped (juvenile) length classes (Sm, M, L) was significant when analyzed using a chi-square 3 x 3 contingency table, (site x length class), (X^2 = 681.1, 3 d.f., and P< 0.0001). Individual z-tests indicated only SW Sm versus JG Sm (z=6.07, P=0.00) and SW L versus JG L (z=2.82, P= 0.00482) were significantly different (Fig. 16).

Finally the percent frequency of lipped conch in relation to erosion levels (N,S,SS) indicated a significant difference when analyzed using a chi-square 3 x 3 contingency table, (site x erosion level), (X^2 = 137.9, 3 d.f., and P< 0.0001). Individual z-tests indicated a significant difference between several individual proportions (Dunn's method); SW N versus JG N (z=5.77, p=0.00), SW N versus DS N (z = 6.56, P=0.00), DS S versus JG S (z=2.24, P=0.0249) (Fig. 17).

A total of 3640 conch (lipped=2952, non-lipped=688) were examined during the abundance survey. The percent frequency of lipped (adult & sub-adult) to non-lipped (juvenile) conch was significantly different in all three zones (z-tests; P<0.05). The results are as follows: Artisinal zone, 91.1% lipped (z=92.3); 10 to 20 m zone, 81.0% lipped (z=8201); and 20 to 30 m zone, 79.2%

lipped (z=2834) (Fig. 18). A chi-square 2 x 3 contingency table was used to determine whether there was a significant difference between the lip proportions in each zone. A significant difference (X^2=14.9, 2 d.f., P=0.0006) was found. Individual chi-squares comparisons between sites indicated significant differences between lipped proportions at ART versus 10-20 m zone (X^2=11.7, d.f.=1, P=0.0006) and ART versus 20-30m zone (X^2=14.2, d.f.=1, P=0.0002). The lipped proportions compared between the 10-20 m and 20-30 m zones did not show a significanct difference (P=0.2621). The overall breakdown of size/age categories in percentage for all zones is Sm (6.8%), M (11.4%), L (0.7%), SA (6.3%), N (25.7%), and S (49.1 %) (Fig. 19). All size/age proportions between zones (e.g. ART vs. 10-20 m) (X^2=231.2, d.f.=8, P<0.0001) and within zones (Sm vs. S) (X^2=231.2, d.f.=8, P<0.0001) exhibited significant differences.

3.3 Estimates of Growth and Age

The size frequency distributions were constructed for nonlipped (juvenile) shell length, lipped shell length, and adult shell lip at SW (Fig. 20,21,22) , DS (Fig. 23,24,25), JG (Fig. 26,27,28) and November abundance survey data (Fig. 29, 30, 31). No juvenile growth estimates could be made for D-shoal due to the lack of individuals encountered (Fig. 23). No individuals were found of less than 100 mm and subsequently the growth and mean shell lengths are extrapolated from growth parameters for the one year old individuals. Frequency distributions for shell length and lip thickness were also constructed for adult conch separated by erosion level (N, S) collected during November abundance survey (Fig. 32,33).

Juvenile mean cohort lengths at SW for one through four-year-old conch are estimted to be 82.6, 144.1, 186.5, and 215.7 mm respectively. Cumulative growth rates (mean growth over the entire life history) for each cohort translated into 226, 197, 170, and 148 microns/day. Growth parameters are estimated to be $\mathbf{L}_{\infty}$ = 280.9 mm, **K** = 0.371, and $\mathbf{t_0}$ = 0.061.

Juvenile mean cohort lengths at JG for one through four-year-old conch are estimated to be 82.6, 148.8, 186.0, and 207.5 mm respectively. Cumulative growth rates for each cohort translated into 226, 204, 169, and 142 microns/day. Growth parameters are estimated to be $\mathbf{L}_{\infty}$ = 238.5 mm, **K** = 0.533, and $\mathbf{t_0}$ = 0.167.

Final estimates of growth come from data gathered in November during the abundance survey. Juvenile mean cohort lengths for one to four year old conch were estimated to be 85.1, 140.4, 170.1, and 185.8 respectively. Cumulative growth rates were 233, 192, 155, and 127 microns/day. Growth parameters are estimated to be $\mathbf{L}_{\infty}$ = 204.0 mm, **K** = 0.628, and $\mathbf{t_0}$ = 0.142.

An attempt was made to use shell lip frequency distributions to obtain growth and age estimates for adult cohorts. Several problems were encountered with this method. The overlap of shell length growth with shell lip thickness growth, overlap of cohorts, bioerosion of the shell and the very wide range of lip thicknesses (4-38 mm) relative to the number in the sample made exact estimates of adult growth parameters and ages difficult. The relative aging by broad categories (N,S) seems to be more effective (Figs. 32, 33).

3.4 Population Density and Abundance

A total of 58 sites were examined in the three zones; seven in ART (Table 17), 40 in 10-20m (Table 18), and 11 in 20-30m (Table 19). and a total area of 17.86 ha (178 640 m) was sampled. The mean density/ha (95% confidence interval) of total conch (juveniles and adults) in each management zone was: ART, 88.57 (6-211); 10-20m, 203.65 (117-297); and 20-30m, 276.64 (179-367) (Table 20). Rank sum tests (Mann-Whitney) found significant differences of conch densities between ART versus 10-20m (P=0.0437) and ART versus 20-30m (P=0.0038). Estimates were also made of the density/ha of each size/age category in each zone (Table 20). The total abundance (95% confidence interval) of conch in each zone was estimated as 3.2 million (0.2-7.8) in ART zone, 41 million (23.5-59.9) in the 10-20m zone, and 102 million (66.2-135.7) in the 20-30m zone (Table 20). Mean densities by management zone, habitat type, and depth are summarized in Table 21. The highest density of conch in relation to habitat was found in algal plain (AP; 270.0 conch/ha) and represented 10% of the sites. The densities for the other major habitats were sand plain (SP), 217.8, Reef (PR+CH), 108.0, and hard plain, HP (CR+H+GS), 86.3 (Table 21). The only significant difference (Rank sum test, Mann-Whitney) found for conch densities between various habitats was SP versus HP (P=0.0177). The highest density of conch in relation to depth was in 24-30m (280.9 conch/ha) followed by 18-23.9m, (220.1 conch/ha), and 12-17.9m (119.5 conch/ha) (Table 21). Rank sum tests (Mann-Whitney) indicated significant differences between densities of conch at 12-17.9m versus 18-23.9m (P=0.0228) and 12-17.9m versus 24-30m (P=0.00433).

3.5 Estimates of Potential Yield (MSY)

The potential yield (MSY) estimates and their confidence limits (95%) are based on the number of adult (normal, stoned) conch available for harvest estimated within the three zones surveyed (Table 20). These were converted to harvested meat weight using a conversion factor of 8.14 meats/kilogram (see Harvest Sector, 3.6). The potential exploitable biomass (95% C.I) in each zone is: 334 MT (27-1004) in ART; 3778 MT (1437-3939) in 10-20 m; and 9223 MT (2954-19 363) in 20-30 m (Table 22). The empirical formula by Gulland (1971) yielded a MSY of 830 MT (265-1742) for the 20-30 m zone. This was added to the 970 MT (731-1044) MSY calculated using Cadima's formula for the previously exploited ART and 10-20 m zone. The calculation based on Cadima's formula used a total catch of 2000 MT for the Y value. This total catch is based on catch records of 1402 MT for the first six months of 1994 as well as an additional harvest of 600 MT which was harvested in the last 3 months of 1994 (Kong, per. com). A total of 1800 MT (996-2786) is estimated to be the MSY for

Pedro Bank for 1995 using the combined empirical formulas of Gulland (1971) and Cadima (in Troodec 1977) (Table 22).

The first area-based estimate of MSY used the estimate of the number of most recently recruiting year class which was considered to be large juveniles (L) and sub-adults (SA) combined (Table 22). These values were again converted to harvested meat weight and summed yielded a value of 1184 MT (359-1954). The final estimate of MSY used yield potential figures from the Caicos Bank having an area of approximately 6200 km^2 and a long history of sustainable conch fishing. The combined estimate of 137 kg/km^2 is derived from commercial MSY value of 540 MT (87 kg/km^2)(Ninnis 1994) and the estimate of local consumption of 312 MT (50 kg/km^2)(Olsen 1985). This value is then applied to the 6086 km^2 area of Pedro Bank, to 30 m in depth, to yield an estimate of 834 MT. All potential yield calculations ranged from 834 MT to 1800 MT (Table 22).

3.6 Harvest Sector

The conch fishery fleet during 1993 and 1994 consisted of two distinct components. The first was the artisinal fleet based on the Pedro Cays. The boats in the artisinal fleet were generally 9 m canoes equipped with 40 hp outboard engines, carrying 2-3 divers and 1-2 tenders (Table 23). The divers generally used free diving techniques to gather conch, however, some have begun to use Hookah gear in an attempt to increase productivity. The conchs were brought to the surface in the shell and "knocked" back at the landing sites on the Pedro cays where large piles of shells have formed. It was very difficult to estimate total catch of the artisinal fleet as the fleet size was in constant flux. The numbers of boats and divers fishing conch, as opposed to lobster or finfish traps changed seasonally as did the specific individuals. Also no specific data collection system was in place to monitor the artisinal catch. Virtually all catch by the artisinal fleet was brought to mainland Jamaica by carrier boats in exchange for currency or supplies to fishermen living on the cays.

The second main component of the conch fishing fleet were the commercial boats that originate largely from the Dominican Republic and Honduras. In these countries conch stocks have been heavily depleted and many boats have switched their operations to Pedro Bank. These boats operate under Jamaican licenses issued to fish processors and exporters in Jamaica. The vessels average 19 m in length, have 20 divers (almost exclusively Dominicans and Hondurans) and generally make eight trips each year (Table 24). These divers knock the conchs on the bottom and bring up only the "dirty" meats to the accompanying canoe or dory which returns to the mother vessel at the end of each day. The average catch per mother vessel is approximately 23.6 MT/trip (50% grade) which translates into a fleet catch of 2435 MT (23.6 MT x 8.6 trips x 12 vessels) (Table 24).

Export data have been available since 1979 (Fig. 34). The export data for 1993 and 1994 were quite accurate due to the requirements of CITES. The total exports of conch meat during 1993, converted to 50% grade weight, was 1785 MT (Table 25). The 1994 export figures available were 1402 MT (Table 25) but only included those occuring up to the end of June when the fishery was temporarily closed for 3 months before reopening in October 1994. The yield during the last three months of the year was unofficially 600 MT which made a total of approximately 2000 MT of exports during 1994. The Director of Jamaican Fisheries confirmed total exports for 1994 were 2051 MT with a value of $8.33 million US. The 1995 export figure was 2132 MT valued at $7.8 million US (Kong, per. comm.)

Approximately 5000 meat weights were collected in several processing plants between 1993 and 1994. These meats were of four different grades (50%, 65%, 85%, 100%) and were classified based on the amount of processing (tissue removal) that had been done at sea or in the plant itself (Table 26). Conversion factors were calculated in an effort to standardize catch and export values (convert all catch and effort to 50% grade) and determine how many conch were actually being removed by the fishery (using the number of conch /kg of meat at any corresponding grade). Based on these methods an estimated 30.8 million conch were removed by the commercial conch fleet during 1993 and 1994. The conversion factors were calculated as 0.85 ("dirty"), 1.00 (50%), 1.11 (65%), 1.25 (85%), and 1.68 (100%) (Table 26). These values are simply the mean meat weight (g) of the 50% grade divided by the mean meat weight of the desired grade conversion. The value calculated for mean "dirty" meat was

142.5g and meat weight (50%) was 121.3 g. These values were lower than meat weights sampled by the author at sea. Mean meat weight (50%) at SW, DS, JG, were 182.4, 149.0, and 135.6 g respectively (Table 9). The potential meat yield per conch seems to be below that sampled at the three major sites and may again indicate the small overall size of conch in the deeper barren areas of the Bank which consitute the majority of the habitat.

4.0 DISCUSSION

4.1 Morphometric Data

The juveniles at the SW and DS study sites had significantly longer shell lengths and heavier total weights than JG. When comparisons were made between length classes at the three sites significant differences were indicated between SW and JG . South-West Cay and perhaps DS (small sample N = 36) seem to have environments that favor growth of juveniles. These environments seem to be those associated with shallow water and seagrass beds which tend to be the preferred habitats of juvenile conch (Randall 1964, Weil and Laughlin 1984, Stoner and Waite 1990) and result in the highest growth rates (Alcolado 1976). Length to weight relationships were highly correlated for juveniles at all three sites as has been observed elsewhere (Randall 1964, Alcolado 1976, Berg 1976, Wood and Olsen 1983, Buckland 1989). The mean length observed for juvenile length classes in the abundance survey was similar to those found at the three major study sites.

The adult conch at DS and JG had significantly different shell lengths, lip thickness, total weight, tissue weight and meat weight than those at SW. This may have been largely due to the distribution of the erosion classes at the sites. South-West Cay adults are larger in all respects except for lip thickness, where as the S and SS dominate at DS and JG. The level of shell erosion was taken into account when only normal adults were compared and significant differences were still observed between SW, DS, and JG adults. South-West Cay adults were the longest in shell length and heaviest individuals on average. The conch with the thickest lips were observed at DS followed by JG. Large thick shelled adult conch tend to dominate deep (>18 m) sites (Coulston et al. 1987, Stoner and Sandt 1992). It would appear that the favorable habitat at SW results in overall larger individuals however these observations may be the result of the juvenile growth period alone and may cease to be a factor once the conch has reached adulthood. The juvenile life history is thought to be the most sensitive to habitat limitations such as food and shelter as illustrated by high mortality at a barren sand site in the Bahamas (Stoner and Sandt 1991b).

Males and females examined morphometricly were found to be significantly different from each other in all respects except lip thickness. Appeldoorn (1986) found that females were larger and heavier at an age of 3.0 years. This study indicated sexual dimorphism continued into later parts of the conch life history. Morphometrics of males and females were compared between the same sex at the three sites and significant differences were seen consistently between SW and JG. South-West Cay conch were larger in all respects except lip thickness. It would appear that favorable conditions at SW result in growth of larger conch.

The correlations of shell length to weight and lip thickness to weight are both quite low when adult conch were used at all three sites. These low correlations are largely due to the cessation of shell length growth at time of sexual maturation (Appeldoorn 1987) as well as the lack of increase in lip thickness due to bioerosion and slowing of growth in older adults (Stoner and Sandt 1992). Stoner and Sandt (1992) often found either zero or negative increase in lip thickness growth for a group of older conch.

Adult morphometrics data collected during the abundance survey confirmed the significance of the erosion categories (N, S) with the N conch longer on average but having thinner lips. Overall conch at abundance survey sites on Pedro Bank were on average shorter in shell length than those found at SW and DS but tended to be similar to those at JG. Normal conch during the abundance survey averaged shell lengths of 209 mm whereas mean shell lengths for SW and DS were 235 mm 215 mm repectively. Favorable conditions of habitat at SW and DS allow conch to be larger than was observed over much of the area studied during the abundance survey. High growth rates in favorable habitats result in larger final shell lengths (Alcolado 1976). The presence of relatively thick lips on conch found during the abundance survey reflects the older nature of the adult stock (N=12.2 mm ,S=21.4 mm) as compared to the SW study site which had a mean lip thickness of 6.0 mm for normal conch and the absence of stoned conch.

4.2 Population Structure

The percent frequency of lipped (adult and sub-adult) and non-lipped (juvenile) conch were significantly different at each study site and tended to reflect whether recent recruitment of juveniles had occured. Scarcity of specimens in particular cohorts may be due to the lack of recruitment during some years (Alcolado 1976). Evidence from the SW study site indicated higher numbers of juveniles (81%) which had recruited into the seagrass areas surrounding the cay. Juvenile abundance, which was low at DS (19%) suggests low recruitment and may be a result of lack of seagrass habitats. Surprisingly high (38%) juvenile abundance was found at JG despite the barren nature (18 m, sand plain) of the site. Similar habitats have been described as sites for deep water spawning with little or no evidence of juveniles (Stoner and Sandt 1992). Hesse reported a 70/30 split between juveniles and adults at a location that had abundant seagrass with a depth of 3-6 m. It would appear from evidence at Pedro that juvenile recruitment can take place in what is thought to be unsuitable juvenile habitats and at a level that is similar with recruitment in much shallower and protected (seagrass) habitats (Hesse 1976). The consistency of these recruitment events is unknown.

The percent frequency of lipped to non-lipped found within the three zones of the abundance survey all indicated significant differences between the zones. All three zones had high levels of adults (>79%) which may indicate low overall recruitment of juveniles on the bank. The lowest levels of juveniles were in the ART zone (9%), however, this may be due to the small number of stations. The lowest abundances for individual age/size categories were for L and Sm juveniles in all zones. These low values for juveniles may again be a reflection of low recruitment levels on Pedro Bank when compared to overall population levels.

Sex ratio was 1:1 and corresponded with reports in the literature (Randall 1964, Alcolado 1976, Blakesley 1977, Buckland 1989). The percent frequency of juvenile length classes at the three major sites may be a reflection of recent recruitment (high levels of Sm at JG) but also may indicate that growth rates are different over the three study sites resulting in a shift in juvenile shell length distribution by class (SW had lowest proportion of Sm juveniles and highest proportion of L juveniles).

The percent frequency of erosion categories between sites may reflect exploitation rates as well as long periods between recruitment events. Normal adults were present in proportionally larger numbers at SW study site. This is possibly due to constant recruitment of juveniles into adult cohorts on an annual basis. The lack of stoned and SS adults may indicate recent or constant exploitation of adults by artisinal fishermen at NE and Middle cays or that S and SS adults tend to move to deeper waters surrounding the SW area as they age. The overall high presence of adults, specifically S and SS at DS indicates that the population at DS has been steadily aging with little imput from new juvenile or younger adult recruits for perhaps 5 or more years.

4.3 Estimates of Growth and Age

The presence of three juvenile year classes or cohorts (2, 3, and 4 year olds) was obvious from the data and analyses of length frequency distribution and their size range and growth rates fall within the limits reported in the literature (Berg 1976; Alcolado 1976; Brownell 1977; Wood and Olsen, 1983; Gibson et al. 1983; Iversen et al., 1987; Appeldoorn 1990, Rathier and Battaglya 1994). The absence of the one year olds (individuals < 100 mm in shell length) was similar to reports in the literature and has been explained by the infaunal nature of that category (Randall 1964, Heese 1979, Appeldoorn 1987, Iversen et al. 1989). The four-year-olds were underrepresented among the juveniles because many of the individuals were in transit between juvenile (unlipped) and adult (lipped) conditions when their lip begins to flare. Growth rates decreased with age as described by the von Bertelanfy growth relationship and were similar to literature reports (Berg 1976; Alcolado 1976; Brownell 1977; Wood and Olsen 1983; Gibson et al. 1983; Iversen et al., 1987; Appeldoorn 1990; Rathier and Battaglya 1994).

The asymptotic maximum length for the SW study site was 280.9 mm compared to 238.5 mm for JG and 204.0 mm for the November survey. Although the calculated length at age for one, two, three, and four year old juveniles was relatively consistent I thought that growth rates and maximum size would tend to be less at JG and other deep barren sites across the Bank. These low values would be a result of the less favorable conditions and limited food resources. It has been well established that length at age are highly variable in mollusks and dependent on habitat characteristics (Holme 1961, Newell and Hidu 1982).

The onset of lip formation, which is presumed to be the beginning sexual maturation (Appeldoorn 1988a, Buckland 1989) , appears to be in the 4th year on Pedro Bank and was older than most values reported (Alcolado 1976, Wefer and Killingley 1980, Iversen et al, 1987, Appeldoorn 1990) which range from 3-4+ years. The mean shell lengths of L juveniles at SW, DS, JG, and November survey ranged from 215 to 206 mm which corresponded to the length at age calculations for the 4th cohort at SW, JG, and from the November survey. Sub-adults, with beginnings (<4.0mm) of lip formation (although shell length increases may still occur) must be at least four years old. The age of first reproduction was therefore suspected to be 5 to 10 months after the onset of lip formation (Appeldoorn 1988a, Buckland 1989) or approximately 4.5+ years old.

Mean longevity appeared to be beyond 12 years based on the large stoned conch population present and is well beyond the 6 to 7 years reported in the literature (Berg 1976, Wefer and Killingely 1980). Wefer and Killingely (1980) used isotope ratios to age a conch (lip thickness=12 mm) at 7 years of age with the lip growth occurring over the last 3 years of life. Considering that if an average of four mm of shell lip thickness was created per year a conch with lip thickness in excess of 38 mm would be at least 13 years old. Stoner and Sandt (1992) state they suspect that longevity estimates by Appeldoorn (1988a) are conservative due to the use of relatively young, uneroded conch to develop the thickness to age relationship. The fact that overall growth slows with age (lip growth would be < 4 mm/year) and bioerosion of the shell and lip is ongoing it is not unreasonable to assume ages of 20+ years of age for very thick lipped, very worn (stoned) conch. The age to lip thickness relationship for conch becomes asymptotic as growth in thickness is offset by bioerosion and dissolution of the outer shell (Stoner and Sandt 1992). This can result in what appears to be zero or even negative net growth rates. The accumulation of large numbers of stoned adults and the lack of naturally dead conch littering the bottom of Pedro Bank suggest that stock accumulation may span age ranges as much as 25 years or more.

4.4 Population Density and Abundance

Conch densities found on the Pedro Bank are high when compared to other studies in the Caribbean region (Table 27). This is a reflection of the limited large scale exploitation of the stock as well as the large accumulated biomass on the Bank (Mahon et al.1991). Despite the low number of sites sampled and the patchy nature of their distribution, conch were found throughout the bank. Other surveys of heavily exploited stocks usually result in many sites with no conch and very low overall densities (Friedlander et al. 1994, Beg and Glazer 1995). Density increases with depth on Pedro Bank, which may reflect long term exploitation in ART zone (20+ years), only recent heavy exploitation in the 10-20 m zone (5+ years), and virtually no exploitation in the 20-30 m zone.

This increasing density with depth is in contrast to values reported where density was highest in 12-18 m depth and decreased significantly beyond 18 m (Friedlander et al. 1995). Despite the high overall densities and abundance of conch, significantly lower figures of juvenile density and abundance are apparent. The proportion of juveniles was low, indicating population structure observed at JG and DS which may be less than ideal. The potential recruitment of juveniles may be high when compared to fisheries in other regions at the present time, however, the ability of the juvenile recruitment to maintain the current standing stock level needed to support the current heavy exploitation is in question.

The vast majority of the sites sampled were sand plain (72%) but had the second highest density in relation to substrate. Highest densities were found in algal plains but these only represented 10% of the sites. Friedlander et al. (1995) in the US Virgin Islands found coral rubble and seagrass supported the highest densities of conch. Algal and sand plain habitats have been described as unsuitable sites for juvenile conch in other localities(Stoner and Sandt 1991b) but seem to support large populations of adult conch on Pedro. Although juveniles were found at sites up to 24 m in depth it is uncertain if such habitats can support large numbers of newly recruited juveniles on an annual basis. These juveniles will be needed to replace large numbers of harvested adults over the next five to ten years.

The majority of the accumulated biomass on Pedro Bank now is stoned conch (56%), which is not the preferred choice of the harvest sector (Kong, personal communication). The decreased volume of the shell and large amount of reproductive tissue in older conch tend to lower the overall meat yield (Randall 1964). The desire for young (normal) adult conch by the harvest sector combined with a possible lack of recruitment suggests that overexploitation of the highest yielding portion of the stock (N adults) may occur. Although recruitment of juveniles seems to occur across the bank, as indicated by observations of juveniles in all three zones, the consistancy and level of this recruitment is suspected to be low. The regular, high recruitment pattern at SW cay is not thought to be reprentative of the Bank.

4.5 Estimates of Potential Yield (MSY)

The calculations of potential yield (MSY), although limited in usefulness reflect the fragile nature of a fishery that has recently entered a "boom" phase. A best case scenario is given by the combination estimate of empirical formulas by Gulland (virgin stock) and Cadima (exploited stock) is 1800 MT (C.I.= 996-2786 MT) and was reached in 1994. It is based on standing stock of normal and stoned conch. Once a majority of the accumulated biomass has been harvested the estimate using the most recently fully recruited year class, 1184 MT (C.I.= 359-1954 MT), will probably be a more realistic value for management purposes. The most conservative estimate uses an application of 137kg/km^2 of meat (Caicos Bank, Turks and Caicos Is.). This MSY is applied to the area of the Pedro Bank (<30 m in depth) for an estimate of 834 MT. Despite the high density of conch found on Pedro Bank caution is recommended. A conservative approach to management will maintain the resource over the long term.

4.6 Habitat Limitations

A great deal of research on conch has been conducted in shallower (6-8 m) shore based environments such as those associated with island shelves or nearby banks: US Virgin Is. (Randall 1964), Turks and Caicos (Hesse 1976), Puerto Rico (Appeldoorn1988a), Bahamas (Berg 1976), Cuba (Alcolado 1976), and Los Roques, Venezuela (Weil and Laughlin 1984). It was informative to study conch biology and ecology in a the population resident on a deep water, isolated, offshore bank such as Pedro.

Morphometric measurements indicated that conch living in shallow, protected sites such as SW Cay were significantly larger individuals. Mean cohort shell lengths, growth rates, and asymptotic maximum length are all higher at SW. Alcolado (1976) working in Cuba found similar relationships although he did not encountered the extremes of depth found in this study. Examination of various juvenile sizes, sex, and adult erosion levels (N, S, SS) also indicated larger individuals at SW Cay. Population structure analysis indicate more regular recruitment events at SW. This is probably due to the shallow nature and abundant food and shelter provided within the seagrass beds, as observed by Alcolado (1976). These regular recruitment events should lead to higher survivability again due to the favorable habitat at SW. Although the highest densities of conch were found over algal plains, where available food and shelter may be greatest for juveniles recruited in the deep regions, the deep barren nature of the Bank does not provide the best overall juvenile habitat. Water depth is particularly important as it acts indirectly to modify habitat through decreased temperature and lower abundance and quality of food (Alcolado 1976).

Conch breeding sites are usually shallow protected sites in sand or coral rubble with low organic content (D'Asaro 1965, Alcolado 1976, Hesse 1976, Weil and Laughlin 1984), however, these may shift to deeper depths as large breeding individuals are removed from shallow areas by fishing pressure (Inversen et al. 1987). No reproductive activity was ever seen during field collections possibly due to the limited suitable spawning habitat available.

Stoner and Sandt (1992) found that conch on sand bottoms tend to have stomachs full of sand indicating a sparse diet of microscopic algae and detritus found within the substrate. Also the harder, calcareous algae (*Halimeda, Penicillus, Udeota*) that dominate on the deep flats tend to be rejected by conch (Alcolado 1976). The presence of both large amounts of sand (sand dominating Pedro conch stomachs) as well as the calcareous algae dominating much of the Pedro Bank substrate (although spare) tend to indicate that Pedro Bank is poor habitat with respect to conch food resources.

It seems clear that the majority of Pedro Bank provides less than ideal habitat for conch as compared to other heavily exploited areas in the Caribbean. The lower growth, smaller size, lack of nursery and breeding areas, and limited food resources indicate a habitat-limited environment for conch. The isolated nature of the bank may even lower the potential for drifting larvae from other areas of the Caribbean to recruit to Pedro. Despite these limitations conch are abundant due primarily to limited exploitation by man. Ultimately the level of recruitment defines the harvest that can be sustainably removed from Pedro Bank and habitat limitations define the level of potential future recruitment to Pedro Bank.

4.7 Harvest Sector

The present harvest level (approximately 2000 MT annual) and the commercial fleet size described (12 vessels) is probably the upper limit that the resource can support. The large confidence intervals indicated for both density and potential yield estimates suggests that management be conservative until subsequent research makes better predictions of density, potential yields, and recruitment possible. The harvest levels for the artisinal sector are poorly known; and an effort should be made to correct the problem. It has been suggested that the artisinal sector receive as much as 20% of any total harvest restriction (Kong, per. comm.).

This study of meat grades provides the only standardization to date for export figures and may allow for possible enforcement of future minimum regulations directly at the plant. The meat weights (50%) obtained at sea were higher than those determined at the plant. The difference suggests either meat yields over the majority of the bank are below that of juvenile garden, where the lowest meat yield in this study were obtained, or that immature conch may be being harvested.

The mean weight of uncleaned ("dirty") meats from Pedro were 142.5 g which is lower than similar measures of "dirty" meat weights reported from other localities: Randall (1964), 246g and Nichols and Jennings-Clark (1994), 329g. This again provides evidence of the smaller size of conch overall and a population that is largely made up of lower meat yielding stoned (older) adults (reduced volume of the shell as shell is laid down in the aperature).

4.8 Management Strategies

The choice of which specific management measures are used and in what combination is a result of three factors: First, the state of the stock and the potential yield; second, the specific nature of the fishery (location, details of the harvest sector, use of the resource); third, the resources available to the management authority. The state of the Pedro Bank conch stock is unique in several ways. First there is an accumulation of conch that suggest the the stock is in a virgin state. The stock includes an abundance of old individuals which have previously been thought to be rare and account for the high present harvest levels. Pedro Bank may have a poor level of recruitment and reduced breeding activity due to habitat limitations. The harvest at present can be maintained at a high level due to the accumulation of adult biomass but over the long term the MSY could be exceeded. Unfortunately management is restricted because the Jamaican Fisheries Divsion has limited resources for monitoring, enforcement, and research. These factors create a situation in which the stock is difficult to assess, monitor, and maintain. Present regulations for conch include: (1) a closed season from July 1st to October 31st each year and; (2) a maximum harvest level (export value) of 2000 MT to be reduced by 100 MT each year. I suggest other specific management measures as follows could be effective in securing the resource for future generations of Jamaican fishers.

The use of a minimum size restrictions allows managers effectively to limit catch by excluding some portion of the stock from harvest. Traditionally minimum shell length has been used to exclude juveniles from the fishery. However, it is clear that this would be a poor choice since the shell lengths of adults on Pedro vary so greatly and often overlap with larger juvenile shell lengths. A simple solution appears to be the use of a fully developed lip (>4.0 mm) as a minimum size restriction. The restriction would protect all juveniles regardless of shell length. Because of the remoteness of the fishing grounds and the limited resources of the Fisheries Division it may be better to use meat weight as a minimum size restriction as these can be easily checked on the mainland directly at the processing plants. Many countries including Antigua, Belize, Columbia, Dominica, Grenada, St. Lucia, and Turks and Caicos have some meat weight minimum (Tewfik 1995). The preliminary information for meat weights and conversion factors to the various grades have been made available in this study. Appeldoorn (1994b) makes a compelling argument for abandoning shell length and meat weights as minimum restrictions in favor of lip thickness and presence of mature gonads however certain situations demand flexibility.

Seasonal or area closures can be used to protect a portion of a stock to allow unhindered reproduction. Closed seasons are often enforced during peak reproduction of conch between June and September in many Caribbean countries. These closures can only be effective if a biologically significant portion of the breeding population remains unfished while the season is open. If the harvest levels are too great this protective measure is less effective.

Closed areas, in the form of "Marine Protected Areas", can be a way of preserving important or rare habitats and may include those regions where mature conch congregate for reproduction. Closed areas may also be highly productive nursery grounds or deep-water refugia where older mature conch are protected from normal harvest season outside the reproductive period. Closures must be based on spatial and temporal distributions of specific age classes targeted for protection. This management strategy could only be effective on Pedro Bank once critical spawning and nursery habitats are identified. This may be difficult due to the seemingly random nature of the larval recruitment and reproductive aggregations on the Bank. The closure of certain zones on a rotating basis may allow recovery of heavily fished zones once harvest levels have removed a large portion of the accumulated biomass.

Gear and vessel restrictions are of limited use due to the water depth and the distance the bank is from mainland Jamaica. The majority of the bank is only feasibly harvested using SCUBA and Hookah gear based from larger vessels that can remain at sea for several weeks. Perhaps the only restrictions useful in this case would be an upper limit of divers allowed on each mother vessel and the banning of factory ships, which for the most part forces the catch to be landed and processed at landing sites in Jamaica and processed there. The stock should benefit the people to whom the resource belongs. Even if harvested by extra nationals it would be processed and exported by Jamaicans.

Bulk harvest restrictions refer to the absolute limit of the available stock that can be harvested by any one company, vessel, or fleet in a given time period. The commercial fleet limit now in force, referred to as the total allowable catch (TAC), is based on the yield calculated for a particular level of effort. Such a management measure is quite complex and requires extensive data collection and analysis. Since data is limited for Pedro Bank, I propose that the potential yield calculations could be used in place of the TAC and that the potential yield calculation that best satisfies management be divided between the participating members of the fishery including the artisinal sector.

It has been proposed by the Fisheries Division that those companies that are favorable to the local economy such as the use of Jamaican vessels, crews, divers, plant workers etc. receive bonus shares of the total allowed harvest for that particular season. The division of the harvest and the issuing of the bonus shares would be reviewed on an annual basis along with the potential yield. In addition to the bulk harvest restriction a limited number of parties would be allowed to participate in the fishery, which would ensure that the participants receive a large enough portion of the potential yield to be economically feasible.

4.9 Future Research

I recommend any future work on the Pedro Bank conch stock include the performance of regular surveys to monitor abundance, impact of harvest, and changes in the natural distribution and structure of the stock. A second abundance survey is planned for 1997 prior to opening of the fishery. A large scale tag-recapture program could be iniciated to obtain more accurate estimates of growth, age, mortality, and movements of conch. The collection of harvest information from the artisinal sector would improve MSY calculations. My discovery of large numbers of old conch on Pedro Bank provides opportunity for studies on aging of this portion of the life history perhaps using isotope ratios as done by Wefer and Killingly (1980). In future a large scale study on veliger distribution over the Bank using planktonic samples as well as modeling of currents of the Pedro Bank may help to understand the recruitment pattern (internal vs. external) of larval conch.

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Table 1. Site Descriptions for SW Cay, D-Shoal, and Juvenile Garden on Pedro Bank, Jamaica

SITE	LOCATION	DEPTH	HABITAT TYPE(S)
SW Cay (SW)	16 59 N 77 48 W	6 - 9 m (20-30 ft.)	Patch reefs & coral heads in sand Sea grass areas; *Syringodium* Coral rubble fields; mixed algal spp *Halimeda, Penicillus, Dictyota,* within sand flats, coral rubble
D-Shoal (DS)	16 57 N, 77 55 W	11-14 m (35-45 ft.)	Patch reefs, coral heads, & flats Extensive formations of branching, plate, boulder, and brain corals Scattered sand patches
Juvenile Garden (JG)	17 00 N 78 08 W	18 m (60 ft.)	Flat sand plain with sparse to moderate mixed algal species: *Halimeda, Penicillus, Caulerpa, Avrainillea Ventricaria, Udeota*

Table 2. Substrate categories for sites surveyed on Pedro Bank during November 1994 survey

Category	Description
SP	Sand Plain - flat sand plain w/ sparse algal or macrophyte cover
AP	Algal Plain - flat substrate w/ moderate to good algal cover
SG	Seagrass meadow - flat substrate w/ moderate to good cover of macrophytes (Turtle and Manatee grass)
PR	Patch Reef - isolated coral habitat ranging in size from a small house to a city block
CH	Coral Heads - smaller than patch reef usually dominated by a single colony, scattered amongst sand
CR	Coral Rubble - area of dead, broken coral forming patches
H	Hard bottom - extended area of hard flat substrate
GS	Gorgonian/Soft coral plain - moderate to good cover of soft corals

Table 3. Size/age categories of conch used for sites surveyed on Pedro Bank during the November 1994 survey

Category	Description
Sm	Small juvenile< 150mm
Me	Medium juvenile between 151 and 200 mm
L	Large juvenile > 200 mm
SA	Sub-adult, flared lip < 4 mm thick
N	Normal adult with fully formed lip and minimal to moderate shell erosion
S	Old (stoned) adult with heavy erosion, extremely worn lip

Table 4. Morphometric statistics for unlipped (juvenile) conch collected at three sites on Pedro Bank during 1993-1994

N = Sample size, S.D. = Standard deviation

SHELL LENGTH (LTH) (mm)

Site	N	Mean	S.D.	Range
SW	966	187	28.2	105 - 258
DS	36	186	28.9	123 - 232
JG	344	157.7	28.4	107 - 225

TOTAL WEIGHT (TWT) (g)

Site	N	Mean	S.D.	Range
SW	966	744.4	335.4	100 - 1700
DS	36	696.1	352.9	180 - 1475
JG	344	520.1	309.3	95 - 1730

Table 5. Morphometric statistics for unlipped (juvenile) conch by shell length class collected at three sites on Pedro Bank during 1993-1994

N = Sample size. S.D. = Standard deviation
Sm = Small (< 150 mm)
M = Medium (151 - 200 mm)
L = Large (> 201 mm)

SHELL LENGTH (LTH) (mm)

SITE	CLASS	N	MEAN	S. D.	RANGE
SW	Sm	105	135.3	11.5	105 - 150
	M	510	177.9	14.2	151 - 200
	L	351	215.6	10.9	201 - 258
DS	Sm	7	137.2	7.3	123 - 145
	M	18	187.1	10.2	168 - 199
	L	11	215.1	11.2	201 - 232
JG	Sm	163	131.9	10.3	107 - 150
	M	153	176.3	14.5	151 - 200
	L	28	206.1	4.9	201 - 225

TOTAL WEIGHT (TWT) (g)

SITE	CLASS	N	MEAN	S. D.	RANGE
SW	Sm	105	269.6	147.5	100 - 1410
	M	510	598.4	161.2	245 - 1090
	L	351	1098.6	203.4	695 - 1700
DS	Sm	7	227.1	32.3	180 - 275
	M	18	676.3	243.2	270 - 1330
	L	11	1026.8	244.4	745 - 1475
JG	Sm	163	266.1	134.4	95 - 1730
	M	153	686.6	195.9	345 - 1185
	L	28	1089.1	89.2	850 - 1255

Table 6. Analysis of variance for juvenile conch morphometrics at three sites (SW,DS,JG) for all juveniles and length categories (Sm,M,L)

	Kruskal-Wallis(one way ANOVA)			Specific Comparison	Significan
Measure	H	d.f.	P	(Dunn's)	P<0.05
LTH	212.7	2	<0.0001	SW vs. DS	no
				SW vs. JG	yes
				DS vs. JG	yes
TWT	115.2	2	<0.0001	SW vs. DS	no
				SW vs. JG	yes
				DS vs. JG	yes
LTH Sm	9.7	2	0.0078	SW vs. DS	no
				SW vs. JG	yes
				DS vs. JG	no
LTH M	9.18	2	0.0102	SW vs. DS	yes
				SW vs. JG	no
				DS vs. JG	yes
LTH L	24.9	2	<0.0001	SW vs. DS	no
				SW vs. JG	yes
				DS vs. JG	yes
TWT Sm	1.65	2	0.438	SW vs. DS	no
				SW vs. JG	no
				DS vs. JG	no
TWT M	24	2	<0.0001	SW vs. DS	no
				SW vs. JG	yes
				DS vs. JG	no
TWT L	1.42	2	0.492	SW vs. DS	no
				SW vs. JG	no
				DS vs. JG	no

Table 7. Shell length-weight relationships for non-lipped conch collected at three sites on Pedro bank during 1993-1994

Lengths in millimetres and weights in grams. shell length classes in Table 3
A = intercept, B = slope, R = correlation coefficient, N = Sample size,
LTH = Shell Length, TWT = Total Weight

Relationship	Site & Category	A	B	R	N
Log10 (TWT) = A + B Log10 (LTH)					
	SW ALL	-4.29	3.14	0.949	966
	SW Sm	-4.51	3.24	0.715	105
	SW Me	-4.06	3.03	0.885	510
	SW L	-3.22	2.68	0.728	351
	DS ALL	-4.93	3.41	0.916	36
	DS Sm	-2.75	2.39	0.902	7
	DS Me	-5.66	3.73	0.584	18
	DS L	-6.96	4.27	0.921	11
	JG ALL	-4.64	3.32	0.951	344
	JG Sm	-4.97	3.48	0.857	163
	JG Me	-4.59	3.31	0.929	153
	JG L	-1.31	1.88	0.518	28

Table 8. Morphometric statistics for conch collected on Pedro Bank during November 1994 survey

N = sample size, % of total sample, S.D. = standard deviation

Shell Length (mm)

Size/Age	N	%	Mean	S.D.	Range
Juv	104	13.8	175.2	25.4	105 - 225
Sm	18	2.4	131.7	14.9	105 - 149
Me	73	9.7	179.3	11.5	150 - 199
L	13	1.7	211.9	7.5	200 - 225
SA	24	3.2	207.5	19.2	165 - 245
N	250	33.2	209.4	17.9	150 - 258
S	375	49.8	190.9	18.8	142 - 257

Shell Lip Thickness (mm)

Size/Age	N	%	Mean	S.D.	Range
N	209	35.9	12.2	5.4	4.0 - 30.0
S	373	64.1	21.4	4.4	7.0 - 36.5

Table 9. Morphometric statistics for lipped (adults and sub-adults) conch collected at three sites on Pedro Bank during 1993-1994
All = total unsexed lipped conch, M = Male, F = Female

SHELL LENGTH (LTH) (mm)

Site	Sex	N	Mean	S.D.	Range
SW	ALL	210	223.9	24.2	160 - 274
	M	47	202.4	23.3	160 - 247
	F	43	224.7	22.4	166 - 257
DS	ALL	348	193.5	22.3	147 - 255
	M	99	192.6	21.8	152 - 240
	F	76	202.3	22.1	165 - 248
JG	ALL	215	197.5	18.2	152 - 242
	M	40	182.4	22.2	100 - 221
	F	41	196.8	22.3	152 - 242

LIP THICKNESS (LIP) (mm)

Site	Sex	N	Mean	S.D.	Range
SW	ALL	210	10.1	8.4	0.6 - 38.4
	M	47	15.3	9.1	1.4 - 38.4
	F	43	13.4	8.9	1.0 - 35.7
DS	ALL	348	20.3	6.2	1.6 - 37.0
	M	99	19.8	5.4	3.5 - 31.2
	F	76	19.4	6.1	2.7 - 30.7
JG	ALL	215	15.5	7.9	0.4 - 29.7
	M	40	19.4	5.7	8.0 - 28.9
	F	41	19.8	5.6	7.2 - 28.2

TOTAL WEIGHT (TWT) (g)

Site	Sex	N	Mean	S.D.	Range
SW	ALL	210	1634.1	356.9	880 - 2900
	M	47	1465.4	273.3	885 - 2060
	F	43	1785.3	389.9	950 - 2900
DS	ALL	348	1498.2	342.1	700 - 3070
	M	99	1454.6	322.8	790 - 2280
	F	76	1588.5	373.2	860 - 2445
JG	ALL	215	1393.4	294.1	780 - 2360
	M	40	1277.1	211.9	830 - 1810
	F	41	1531.3	285.8	920 - 2360

Table 9. Continued

SHELL WEIGHT (SHL) (g)

Site	Sex	N	Mean	S.D.	Range
SW	ALL	90	1306.1	296.2	730 - 2485
	M	47	1187.2	230.9	730 - 1665
	F	43	1435.9	307.3	770 - 2485
DS	ALL	175	1250.9	289.1	670 - 2020
	M	99	1204.9	273.4	670 - 2000
	F	76	1310.9	299.6	710 - 2020
JG	ALL	81	1158.2	216.6	720 - 1880
	M	40	1060	167.8	720 - 1520
	F	41	1254.2	217.5	830 - 1880

TISSUE WEIGHT (TISS) (g)

Site	Sex	N	Mean	S.D.	Range
SW	ALL	90	304.1	92.4	125 - 560
	M	47	265.3	76.5	125 - 440
	F	43	346.5	90.4	185 - 560
DS	ALL	175	259.6	81.2	105 - 485
	M	99	241.3	79.8	105 - 485
	F	76	283.4	77.2	150 - 485
JG	ALL	81	238.9	80.8	95 - 450
	M	40	218	62.6	120 - 335
	F	41	259.3	91.5	95 - 450

MEAT WEIGHT (MEAT) (g)

Site	Sex	N	Mean	S.D.	Range
SW	ALL	90	182.3	52.7	80 - 325
	M	47	159.4	43.1	80 - 265
	F	43	207.4	51.2	115 - 325
DS	ALL	175	148.9	49.6	50 - 360
	M	99	139.29	51.6	50 - 360
	F	76	161.5	44.1	85 - 285
JG	ALL	81	135.5	46.58	55 - 255
	M	40	126	37.7	70 - 195
	F	41	144.8	52.6	55 - 255

Table 10. Analysis of variance of adult conch morphometrics between three sites (SW,DS,JG)

Measure	Kruskal-Wallis (one way ANOVA) H	d.f.	P	Specific Comparison (Dunn's method)	Significan P<0.05
LTH	182.7	2	< 0.0001	SW vs. DS	yes
				SW vs. JG	yes
				DS vs. JG	no
LIP	173.2	2	<0.0001	SW vs. DS	yes
				SW vs. JG	yes
				DS vs. JG	yes
TWT	51.2	2	<0.0001	SW vs. DS	yes
				SW vs. JG	yes
				DS vs. JG	yes
SHL	13.2	2	0.0013	SW vs. DS	no
				SW vs. JG	yes
				DS vs. JG	yes
TISS	22.3	2	<0.0001	SW vs. DS	yes
				SW vs. JG	yes
				DS vs. JG	no
MEAT	38.3	2	<0.0001	SW vs. DS	yes
				SW vs. JG	yes
				DS vs. JG	no

Table 11. Analysis of variance of adult conch morphometrics between sexes (m=male,f=female) at three sites (SW, DS, JG)

		Rank Sum test (Mann-Whitney)	
Measure	**Specific Comparison**	**T**	**P**
LTH	SW m vs. f	2412	<0.0001
	DS m vs. f	7545.5	0.0099
	JG m vs. f	1356.5	0.0075
LIP	SW m vs. f	1848.5	0.385
	DS m vs. f	9850.5	0.999
	JG m vs. f	1609.5	0.777
TWT	SW m vs. f	2474	<0.0001
	DS m vs. f	7432.5	0.0251
	JG m vs. f	1206	<0.0001
SHL	SW m vs. f	2451	<0.0001
	DS m vs. f	7434.5	0.0247
	JG m vs. f	1206.5	<0.0001

Table 12. Analysis of variance of adult conch morphometrics between same sexes (m=male) at three sites (SW,DS,JG)

	Kruskal-Wallis (one way ANOVA)			Specific Comparison	Significan
Measure	**H**	**d.f.**	**P**	**(Dunn's method)**	**P<0.05**
LTHm	13.2	2	0.0013	SW vs. DS	no
				SW vs. JG	yes
				DS vs. JG	no
LIPm	9.16	2	0.0102	SW vs. DS	yes
				SW vs. JG	no
				DS vs. JG	no
TWTm	13.5	2	0.0012	SW vs. DS	no
				SW vs. JG	yes
				DS vs. JG	yes
SHLm	11.4	2	0.0034	SW vs. DS	no
				SW vs. JG	yes
				DS vs. JG	yes
LTHf	29.7	2	<0.0001	SW vs. DS	yes
				SW vs. JG	yes
				DS vs. JG	no

Table 13. Morphometric statistics for lipped conch by shell erosion level (N,S,SS) collected at three sites (SW,DS,JG) on the Pedro Bank during 1993-1994

N = Normal , S = Stoned, and SS = Severly Stoned

SHELL LENGTH (LTH) (mm)

SITE	EROSION	N	MEAN	S. D.	RANGE
SW	N	51	235. 4	16.2	202 - 265
DS	N	45	215.2	20.3	159 - 242
	S	59	189.5	18.1	152 - 248
	SS	19	185	15.2	158 - 212
JG	N	86	204.9	12.2	170 - 233
	S	39	189.6	17.1	157 - 233
	SS	42	176.1	14.7	152 - 204

LIP THICKNESS (LIP) (mm)

SITE	SHL ER.	N	MEAN	S. D.	RANGE
SW	N	51	6.03	4.6	0.6 - 22.9
DS	N	45	16.2	5.8	2.7 - 29.8
	S	59	21.4	3.1	13.8 - 30.7
	SS	19	22.7	4.6	12.1 - 30.5
JG	N	86	9.6	6.2	0.4 - 24.8
	S	39	21.9	4.1	10.8 - 29.7
	SS	42	23.4	2.9	16.8 - 28.9

TOTAL WEIGHT (TWT) (g)

SITE	SHL ER.	N	MEAN	S. D.	RANGE
SW	N	51	1689.3	353.9	880 - 2385
DS	N	45	1707.5	361.1	860 - 2445
	S	59	1421.9	303.9	790 - 2430
	SS	19	1450.5	373.3	860 - 2270
JG	N	86	1356.3	308.7	780 - 2195
	S	39	1479.4	290.2	940 - 2060
	SS	42	1309.8	264.2	830 - 1980

Table 14. Analysis of variance of adult conch morphometrics between erosion categories (N,S,SS) and between normal (N) adults at three sites (SW,DS,JG)

	Kruskal-Wallis(one way ANOVA)			Specific Comparison	Significan
Measure	H	d.f.	P	(Dunn's)	P<0.05
LTH	173.4	2	< 0.0001	N vs. S	yes
				N vs. SS	yes
				S vs. SS	yes
LIP	191.5	2	<0.0001	N vs. S	yes
				N vs. SS	yes
				S vs. SS	no
TWT	13.2	2	<0.0001	N vs. S	no
				N vs. SS	yes
				S vs. SS	no
LTH N	74.3	2	<0.0001	SW vs. DS	yes
				SW vs. JG	yes
				DS vs. JG	yes
LIP N	50.5	2	<0.0001	SW vs. DS	yes
				SW vs. JG	yes
				DS vs. JG	yes
TWT N	37.6	2	<0.0001	SW vs. DS	yes
				SW vs. JG	yes
				DS vs. JG	no

Table 15. Shell length-weight relationships for lipped conch collected at three sites on Pedro Bank during 1993-1994

Lengths in millimetres and weights in grams. Erosion categories in Table 13.
A = intercept, B = slope, R = correlation coefficient, N = Sample size
LTH = Shell Length, TWT = Total Weight, SHL = Shell Weight, TISS = Tissue Wt. viscera, and MEAT = Tissue - viscera (50% grade of processing, see Table 26)

Relationship	Site & Category	A	B	R	N
Log10 (TWT) = A + B Log10 (LTH)					
	SW ALL	0.56	1.12	0.698	90
	SW M	1.06	0.91	0.563	47
	SW F	-0.28	1.51	0.723	43
	SW Nr	-2.26	2.31	0.725	51
	DS ALL	-0.13	1.44	0.829	123
	DS M	-0.75	1.71	0.836	99
	DS F	-0.62	1.65	0.744	76
	DS Nr	-0.93	1.78	0.753	45
	DS S	-1.44	2.01	0.877	59
	DS SS	-3.15	2.78	0.849	19
	JG ALL	0.07	1.34	0.584	167
	JG M	1.83	0.56	0.457	40
	JG F	0.03	1.37	0.856	41
	JG Nr	-2.62	2.62	0.694	86
	JG S	-1.11	1.87	0.832	39
	JG SS	-1.24	1.94	0.831	42
Log10 (SHL) = A + B Log (LTH)					
	SW ALL	0.37	1.18	0.648	90
	SW M	1.12	0.84	0.501	47
	SW F	0.07	1.31	0.652	43
	DS ALL	-0.42	1.53	0.733	175
	DS M	-0.46	1.54	0.748	99
	DS F	-0.31	1.48	0.689	76
	JG ALL	1.18	0.83	0.595	81
	JG M	1.97	0.46	0.397	40
	JG F	0.78	1.01	0.703	41

Table 15. Continued

Relationship	Site & Category	A	B	R	N
Log 10 (TISS) = A + B Log10 (LTH)					
	SW ALL	-2.63	2.19	0.861	90
	SW M	-2.41	2.09	0.826	47
	SW F	-2.41	2.11	0.829	43
	DS ALL	-3.01	2.36	0.829	175
	DS M	-3.41	2.53	0.857	99
	DS F	-2.08	1.96	0.763	76
	JG ALL	-1.98	1.91	0.711	81
	JG M	-0.11	1.07	0.481	40
	JG F	-4.51	3.01	0.912	41
Log10 (MEAT) = A + B Log10 (LTH)					
	SW ALL	-2.54	2.05	0.856	90
	SW M	-2.21	1.91	0.815	47
	SW F	-2.38	1.99	0.829	43
	DS ALL	-3.37	2.41	0.817	175
	DS M	-3.71	2.55	0.818	99
	DS F	-2.61	2.08	0.795	76
	JG ALL	-2.51	2.02	0.739	81
	JG M	-0.83	1.29	0.558	40
	JG F	-5.03	3.13	0.921	41

Table 16. Shell lip thickness-weight relationships for lipped conch collected at three sites on Pedro Bank during 1993-1994

Lip thickness in millimetres and weights in grams. Erosion categories in Table 13.
A=intercept, B=slope, R=correlation coefficient, N = Sample size,
LIP = Lip Thickness, TWT = Total Weight, SHL = Shell Weight, TISS=Tissue Weight including viscera , & MEAT = Tissue - viscera

Relationship	Site & Category	A	B	R	N
Log10 (TWT) = A + B Log10 (LIP)					
	SW ALL	3.15	0.065	0.148	90
	SW M	3.15	0.004	0.015	47
	SW F	3.18	0.064	0.241	43
	SW N	3.11	0.161	0.611	51
	DS ALL	3.09	0.061	0.173	123
	DS M	3.18	-0.022	0.035	99
	DS F	3.04	0.119	0.238	76
	DS N	3.05	0.145	0.311	45
	DS S	2.64	0.381	0.251	59
	DS SS	1.91	0.921	0.758	19
	JG ALL	3.01	0.111	0.386	167
	JG M	3.07	0.024	0.051	40
	JG F	3.38	0.156	0.286	41
	JG N	2.97	0.179	0.651	86
	JG S	2.87	0.221	0.221	39
	JG SS	2.64	0.344	0.225	42
Log10 (SHL) = A + B Log (LIP)					
	SW ALL	3.05	0.051	0.181	90
	SW M	3.02	0.041	0.161	47
	SW F	3.06	0.087	0.335	43
	DS ALL	2.97	0.093	0.166	175
	DS M	3.01	0.043	0.068	99
	DS F	2.93	0.143	0.295	76
	JG ALL	3.01	0.041	0.078	81
	JG M	2.89	0.104	0.231	40
	JG F	3.14	-0.039	0.081	41

Table 16. Continued

Relationship	Site & Category	A	B	R	N
Log10 (TISS) = A + B Log (LIP)					
	SW ALL	2.58	-0.113	0.286	90
	SW M	2.57	-0.154	0.403	47
	SW F	2.56	0.039	0.118	43
	DS ALL	2.51	-0.092	0.121	175
	DS M	2.62	-0.204	0.225	99
	DS F	2.42	0.016	0.027	76
	JG ALL	2.97	-0.487	0.477	81
	JG M	2.73	-0.326	0.378	40
	JG F	3.24	-0.668	0.597	41
Log10 (MEAT) = A + B Log10(LIP)					
	SW ALL	2.35	-0.106	0.285	90
	SW M	2.34	-0.141	0.398	47
	SW F	2.34	-0.039	0.126	43
	DS ALL	2.28	-1.001	0.126	175
	DS M	2.34	-0.178	0.187	99
	DS F	2.21	-0.018	0.031	76
	JG ALL	2.71	-0.469	0.451	81
	JG M	2.48	-0.315	0.354	40
	JG F	2.95	-0.641	0.555	41

Table 17. Mean density of conch (per hectare) occurring by site in the Artisinal (ART) zone on Pedro Bank during the November 1994 survey
Size/age categories (Table 3), Substrate categories (Table 2)

Site	Location		Sm	Me	L	SA	N	S	TOTAL	DEPTH	Substrate types MAIN	2NDARY
			Size/Age Category									
7	17°06'N	77°44'W	0	16	0	19	26	75	136	18	SP	GS
10	16°57'N	77°50'W	0	3	0	6	0	71	80	13	SP	SP
11	16°57'N	77°51'W	0	10	0	0	10	45	65	15	GS	CH
14	16°58'N	77°55'W	0	19	0	23	55	10	107	12	CH	CR
15	16°57'N	77°55'W	0	3	0	0	42	166	211	12	PR	CH
22	16°52'N	78°04'W	0	3	0	3	6	3	15	n/a	n/a	n/a
26	16°51'N	78°07'W	0	0	0	0	3	3	6	12	CH	GS
Total			0	54	0	51	142	373	620			
Mean			0	7.71	0	7.29	20.29	53.29	88.57	13.7		
Standard deviation			0	7.39	0	9.69	21.33	58.44	71.22	2.42		

Table 18. Mean density of conch (per hectare) occuring by site in the 10-20 m zone on Pedro Bank during November 1994 survey

Size/age categories (Table 3), Substrate categories (Table 2)

Site	Location		Size/Age Category						TOTAL	DEPTH	Substrate types	
			Sm	Me	L	SA	N	S			MAIN	2NDARY
2	17°04'N	77°30'W	0	0	0	0	6	0	6	15	H	GS
3	17°02'N	77°33'W	0	16	6	16	26	0	64	15	H	GS
5	17°05'N	77°34'W	10	6	0	0	13	23	52	18	SP	CR
6	17°01'N	77°38'W	0	0	0	0	0	0	0	12	H	GS
8	17°05'N	77°50'W	0	0	0	0	6	182	188	18	AP	AP
13	17°04'N	77°54'W	0	0	0	3	23	162	188	n/a	n/a	n/a
16	17°03'N	77°58'W	0	16	3	19	88	62	188	17	SP	SP
17	17°02'N	77°55'W	58	42	0	6	23	32	161	15	SP	SP
18	17°02'N	78°01'W	3	65	0	36	65	91	260	17	AP	AP
19	17°06'N	78°02'W	10	6	0	0	19	318	353	n/a	n/a	n/a
20	17°04'N	78°02'W	13	49	0	49	68	153	332	18	AP	AP
23	17°03'N	78°00'W	10	23	0	16	32	101	182	20	SP	SP
24	17°00'N	78°07'W	88	91	0	26	42	49	296	16	AP	corals
25	16°57'N	78°06'W	29	29	0	10	16	10	94	18	SP	SP
27	16°53'N	78°08'W	0	0	0	3	3	10	16	18	SP	SP
28	16°06'N	77°50'W	0	19	0	13	52	78	162	n/a	n/a	n/a
29	16°58'N	78°09'W	6	6	0	16	32	49	109	16	SP	SP
30	16°50'N	78°10'W	6	3	0	6	16	55	86	20	SP	CH
31	16°49'N	78°11'W	0	0	0	0	0	36	36	20	SP	CH
32	16°51'N	78°11'W	10	0	0	0	0	13	23	18	SP	CH
33	16°52'N	78°12'W	0	10	0	3	19	198	230	20	SP	SP
35	16°53'N	78°14'W	0	3	0	3	29	179	214	20	SP	SP
37	16°53'N	78°17'W	6	10	3	10	123	62	214	18	SP	SP
38	17°04'N	78°17'W	0	62	13	13	169	81	338	20	SP	CR
39	17°03'N	78°17'W	6	117	26	42	182	81	454	18	SP	CR
40	17°02'N	78°18'W	305	55	0	26	10	32	428	n/a	n/a	n/a
41	16°58'N	78°18'W	0	3	0	6	16	39	64	18	SP	SP
42	16°55'N	78°18'W	0	6	0	6	114	45	171	18	SP	SP

Table 18. Continued.

Site	Location		Sm	Me	L	SA	N	S	TOTAL	DEPTH	MAIN	2NDARY
43	17°03'N	78°20'W	78	29	0	0	10	0	117	20	SP	CR
44	16°51'N	78°21'W	0	0	0	0	45	283	328	18	SP	SP
48	16°51'N	78°26'W	0	0	0	0	88	283	371	18	SP	CR/GS
50	16°58'N	78°28'W	0	36	0	26	221	88	371	19	SP	SP
51	16°57'N	78°29'W	3	36	0	23	143	94	299	20	SP	SP
52	16°56'N	78°28'W	6	13	0	13	205	78	315	n/a	n/a	n/a
53	17°01'N	78°30'W	0	19	6	29	146	97	297	20	SP	SP
54	16°59'N	78°29'W	0	6	3	19	237	104	369	20	SP	SP
55	16°56'N	78°32'W	0	10	0	3	205	175	393	20	SP	SP
56	16°57'N	78°37'W	6	16	0	16	26	0	64	18	SP	CR/GS
57	16°59'N	78°39'W	13	6	0	55	58	175	307	20	SP	SP
60	16°54'N	78°45'W	0	0	0	0	0	6	6	n/a	n/a	n/a
Total			666	808	60	512	2576	3524	8146			
Mean			16.65	20.2	1.5	12.8	64.4	88.1	203.65	18.1		
Standard deviation			50.87	26.75	4.68	14.29	70.92	83.21	134.28	1.92		

Table 19. Mean density of conch (per hectare) occurring by site in 20-30 m zone on Pedro Bank during the November 1994 survey

Size/age categories (Table 3), Substrate categories (Table 2)

			Size/Age Category								Substrate Type	
Site	Location		Sm	Me	L	SA	N	S	TOTAL	DEPTH	MAIN	2NDARY
1	17°07'N	78°31'W	0	3	0	0	0	13	16	22	H	GS
4	16°53'N	77°39'W	0	0	0	0	0	179	179	24	SP	sponges
34	17°06'N	78°10'W	10	3	0	19	23	188	243	21	SP	SP
36	17°06'N	78°14'W	65	58	0	29	42	114	308	24	n/a	n/a
45	16°59'N	78°22'W	13	146	3	91	32	65	350	21	SP	SP
46	17°09'N	78°20'W	0	3	0	0	0	273	276	24	AP	coral
47	17°10'N	78°23'W	3	3	0	6	10	224	246	24	SP	SP
49	17°03'N	78°29'W	39	211	13	16	88	101	468	21	SP	SP
58	17°00'N	78°47'W	3	58	0	16	104	55	236	24	SP	SP
59	16°55'N	78°46'W	0	0	0	0	0	367	367	27	CR	SP
61	16°50'N	78°46'W	0	0	0	0	16	338	354	30	SP	PR
Total			133	485	16	177	315	1917	3043			
Mean			12.09	44.09	1.45	16.09	28.64	174.3	276.64	23.82		
Standard deviation			21.04	71.57	3.93	26.8	36.35	117.3	117.61	2.75		

Table 20. Estimates of mean density per ha and total abundance by zone on Pedro Bank during November 1994 survey

		Size/Age Category						
Zone	Area	Sm	Me	L	SA	N	S	Total
Art*	7 sites	0	7.71	0	7.29	20.29	53.29	**88.57**
							C.I.	6-211
Art*	37 000 ha	0	285 270	0	269 730	750 730	1 971 730	3 277 090
							C.I.	0.2-7.8 mil.
10 - 20 m	40 sites	16.65	20.2	1.5	12.8	64.4	88.1	**203.65**
							C.I.	117-297
10 - 20 m	201 700 ha	3 358 305	4 073 340	302 550	2 581 760	12 989 480	17 769 770	41 076 205
							C.I.	23.5-59.9 mil
20 - 30 m	11 sites	12.09	44.09	1.45	16.09	28.64	174.27	**276.64**
							C.I.	179-367
20 - 30 m	370 000 ha	4 473 300	16 313 300	536 500	5 953 300	10 596 800	64 479 900	102 356 800
							C.I.	6.2-135.7mi

C.I. - confidence interval (95%), non parametric based on median of samples at each station

* Artisinal zone - area in proximity to Pedro cays that includes all of 0-10 m zone as well as some areas of 10 - 20 m depth but not included in that zone

ha = hectare (10 000 squ. m)

mil = million

Table 21. Conch densities by management zones (ART, 10-20m, 20-30m), substrate type (SP,AP,SG,Reef. HP), and depth zones (0-11.0m,12-17.9m,18-23.9m.24-30m) on Pedro Bank during the November 1994 survey

S.D.=standard deviation, N=no. of sites,%=percentage of sites. Substrate types are defined in Table 3.

	Mean density conch/hectare	S.D.	Median	N	%
Management Zones					
ART (artisinal)	88.6	71.2	80	7	12
10-20m	203.7	134.3	188	40	69
20-30m	276.6	117.6	276	11	19
Substrate Types					
Sand Plain (SP)	217.8	128	214	36	72
Algal Plain (AP)	270	53.3	276	5	10
Seagrass (SG)	n/a	n/a	n/a	n/a	n/a
Reef*	108	102.5	107	3	6
Hard Plain#	86.3	104.4	40	6	12
Depth (m)					
0-11.9	n/a	n/a	n/a	n/a	n/a
12-17.9	119.5	97.3	107	13	25
18-23.9	220.1	138.9	214	31	61
24-30	280.9	67.2	276	7	14

Notes

*** Reef= Patch reef (PR) and Coral Heads (CH)**

 # Hard Plain= Coral rubble (CR), Hard (H), and Gorgonian/Soft coral (GS)

Table 22. Potential yield calculations (MSY) for the Pedro Bank conch fishery based on November 1994 survey data

	Method	Potential Exploitable Stock (N+S)		C.I.	MSY	C.I.	Comments
1	Gulland (1971) MSY=XMBv	20-30 m	9223 MT	2954-19 363 MT	**830 MT**	265-1742 MT	only 20-30 m zone virgin stock
2	Cadima (in Troadec 1977) MSY=X(Y+MBe)	ART 10-20 m Total	334 MT 3778 MT 4112 MT	27-1004 MT 1437-3939 MT	**970 MT**	731-1044 MT	estimate of 2000 MT, 1994 harvest in ART 10-20 m
	1 + 2				**1800 MT**	996-2786 MT	virgin (20-30m) + exploited
3	Fully recruited year class (L + SA)	ART 10-20 m 20-30 m Total	33 MT 354 MT 797 MT 1184 MT	13-104 MT 74-396 MT 272-1454 MT	**1184 MT**	359-1954 MT	SA thought to perhap be part of the L juvenile year class
4	Caicos Bank comparison				**834 MT**	n/a	apply 137 kg/km squ. to area of Pedro Bank (6086 squ. km to 30 m in depth)

C.I = confidence interval (95%), non-parametric based on median of samples in survey

Table 23. Artisinal diver interview information obtained at Pedro Cays during 1993-1994 surveys

Vessel length/engine	Crew	Dive method	% Time spent diving conch/lobs	Mean depth m	Days/ week	Catch/ dive	No. dives /day
9m / 40hp	3 divers / 1tender	Free	90 / 10	13.7	5	5 in shell	100
9m / 40hp	2 divers / 2 tenders	Hookah	75 / 25	16.5	5	23 kg meats	2x1.5hrs
9m / 40hp	2 divers / 2 tenders	Hookah	50 / 50	18.3	5	23 kg meats	5x0.75hrs
9m / 40hp	3 divers / 1tender	Free	100 / 0	13.7	4	6 in shell	100
9m / 40 hp	3 divers / 1 tender	Free	50 / 50	20.1	6	6 in shell	180
10m / 75hp	2 divers / 2 tenders	Hookah	60 / 40	18.3	7	36 kg meats	3x2.0hrs
9m / 40hp	2 divers / 1tender	Free	100 / 0	9.1	4	4 in shell	20
9m / 40hp	2 divers / 2 tenders	Free	80 / 20	12.8	5	5 in shell	80
9m / 40hp	1 diver / 1 tender	Free	50 / 50	14.6	7	5 in shell	100
9m / 40hp	4 divers / 1 tender	Free	75 / 25	18.3	4	6 in shell	125
9m / 40hp	5 divers / 1 tender	Free	50 / 50	16.5	4	5 in shell	70
9m / 40hp	2 divers / 2 tenders	Hookah	na	22	5	23 kg meats	3x0.75hrs
9m / 40hp	3 divers / 1 tender	Free	na	14.6	5	6 in shell	90
Mean	2.6 divers/1.4 tender	Free	70 / 30	14.8	5.1	5.3 in shell	96
	"	Hookah	"	18.8	"	26.3 kg	3.25

Table 24. Commercial conch vessel information obtained for Pedro Bank during 1993-1994 surveys
Derived from vessel catch forms. Some vessels submitted more than one form and mean values were calculated

Vessel	Length (m)	Vessel Origin	Dive Gear	Mean no. of divers	Mean no. of dorys	Trips/ year	Dive hrs/ day/diver	Catch# (Kg)	Grade (%)
Afeliy	52	Russia *	Hookah	27.6	14.7	10	na	65189	85
Dona Maria	na	Dom. Rep.	Hookah	na	na	na	na	8759	85
Geronimo	18.5	Dom. Rep.	Hookah	na	na	na	na	40823	50
Happy Boy	20.5	Dom. Rep.	Hookah	22	11	8	7	13852	50
High Isles	22	Jamaica	Hookah	14.1	7.1	9	8	44507	50
Hope	23	Honduras	SCUBA	17.6	17.6	8	6	8989	65
Pawanka II	na	na	na	na	na	na	na	11228	85
Sea Crest	17	Dom. Rep.	Hookah	10.5	5.3	8	7.5	29907	50
Southwest	18.5	Honduras	SCUBA	21.6	21.6	9	4.5	12464	85
Tiburon Walker	25.5	Dom. Rep.	Hookah	na	na	na	na	13678	85
Tri-C	24	Honduras	SCUBA	20	20	8	7.9	14361	various
Two Brothers	na	Dom. Rep.	Hookah	na	na	na	na	20140	65
Mean	**19.2**			**19.1**	**13.9**	**8.6**	**6.8**	**23633**	

given in 50% grade equivalent weight, see table ?.
* divers from Dominican Republic (Dom. Rep.)

Table .Registered Exports of conch from Jamaica, 1993-1994, by meat grade

All values are in Kilograms and are convertted to equivelent weight for 50% grade meat (Table)

1993

	Meat grades				
Month	**50**	**65**	**85**	**100**	**Total**
Jan	0	0	0	0	0
Feb	50033	0	0	0	50033
Mar	168642	0	0	11455	180097
Apr	68182	0	0	0	68182
May	11363	50103	0	0	61466
Jun	76800	130351	17021	0	224172
Jul	51616	94158	50060	24	195858
Aug	138251	124962	32825	64779	360817
Sept	43245	53666	0	23495	120406
Oct	0	47056	16274	3825	67155
Nov	87570	135678	7073	13538	243859
Dec	50338	124188	39322	0	213848
Total	746040	760162	162575	117116	**1785893**

1994

	Meat grades				
Month	**50**	**65**	**85**	**100**	**Total**
Jan	0	183813	0	0	183813
Feb	97490	119507	0	18454	235451
Mar	20000	28541	0	27971	76512
Apr	0	82084	0	0	82084
May	0	295747	0	122696	418443
Jun	139000	231937	0	35113	406050
Total	256490	941629	0	204234	**1402353**

Table 26. Conch meat processing information based on 5000 meat collections from processing plants receiving vessel catches directly from Pedro Bank during 1993-1994

Grade	Tissue Loss	Total Loss (%)	Mean Yield	Conversion factor
"Dirty"	none, animal simply removed from shell	0	142.5 g/meat 7.02/Kg (3.18/lbs)	0.85
50%	operculum (claw) viscera (bag)	14.9	121.3 g/meat 8.14/Kg (3.74/lbs)	1.00
65%	eye stalks,proboscis & part of mantle	23.5	108.9 g/meat 9.18/Kg (4.16/lbs)	1.11
85%	remaining mantle skin, and verge	32.1	96.7 g/meat 10.34/Kg (4.69/lbs)	1.25
100%	only pure white meat remains	49.4	72.05g/meat 13.88/Kg (6.3/lbs)	1.68

NOTES

Grade refers to level to which the meat has been cleaned and are industry standard
Tissue loss descriptions are cumulative
Conversion factor use 50% grade as base unit
All information on processed meat data was collected at processing plants except for "dirty" grade simply being total tissue (TISS) removed from a conch and is used for comparison to tissue (TISS) data collected at sea

Table 27. Mean densities of *Strombus gigas* in selected sites throughout the Caribbea

Location	Density (conch/ha)	Reference
Bahamas		
Little Bahamas Bank	28.5	Smith and Neirop 1984
Great Bahamas Bank	20.79	Smith and Neirop 1984
Protected Bank	53.6	Stoner and Ray, in prep
Protected Shelf	96	Stoner and Ray, in prep
Bermuda		
1988	0.52	Berg et al. 1992
1989	2.94	Berg et al. 1994
Florida Keys		
1987-88	2.4	Berg and Glazer 1995
1990	1.54	Berg and Glazer 1995
Honduras, Cayos Cochinos	14.6	Tewfik, in prep
Jamaica, Pedro Bank		
Artisinal zone (0 - 10 m)	88.57	This study
Industrial zone (10 - 20 m)	203.65	This study
20 - 30 m	276.64	This study
Puerto Rico	8.11	Torres Rosado 1987
U.S. Virgin Islands		
St. Croix	7.6	Wood and Olsen 1983
St. Thomas/St. Johns	9.7	Wood and Olsen 1983
St. Thomas/St. Johns	12.25	Friedlander et al. 1994
Venezuela		
Protected	2130	Weil and Laughlin 1984
Fished	900	Weil and Laughlin 1984

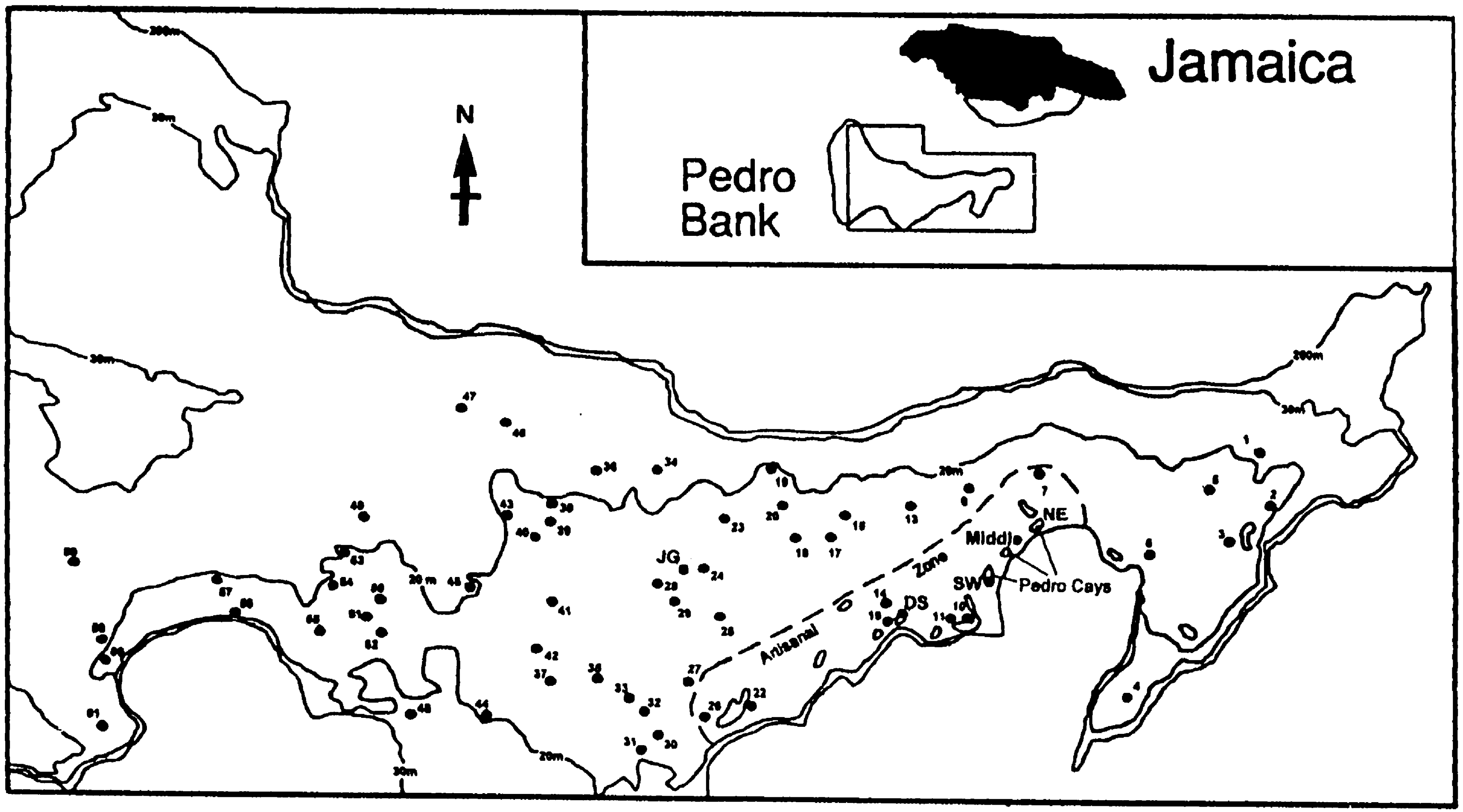

Figure 1. Site locations for repeated sampling (SW Cay, D-Shoal, Juvenile Garden) and the November 1994 survey on Pedro Bank, Jamaica.

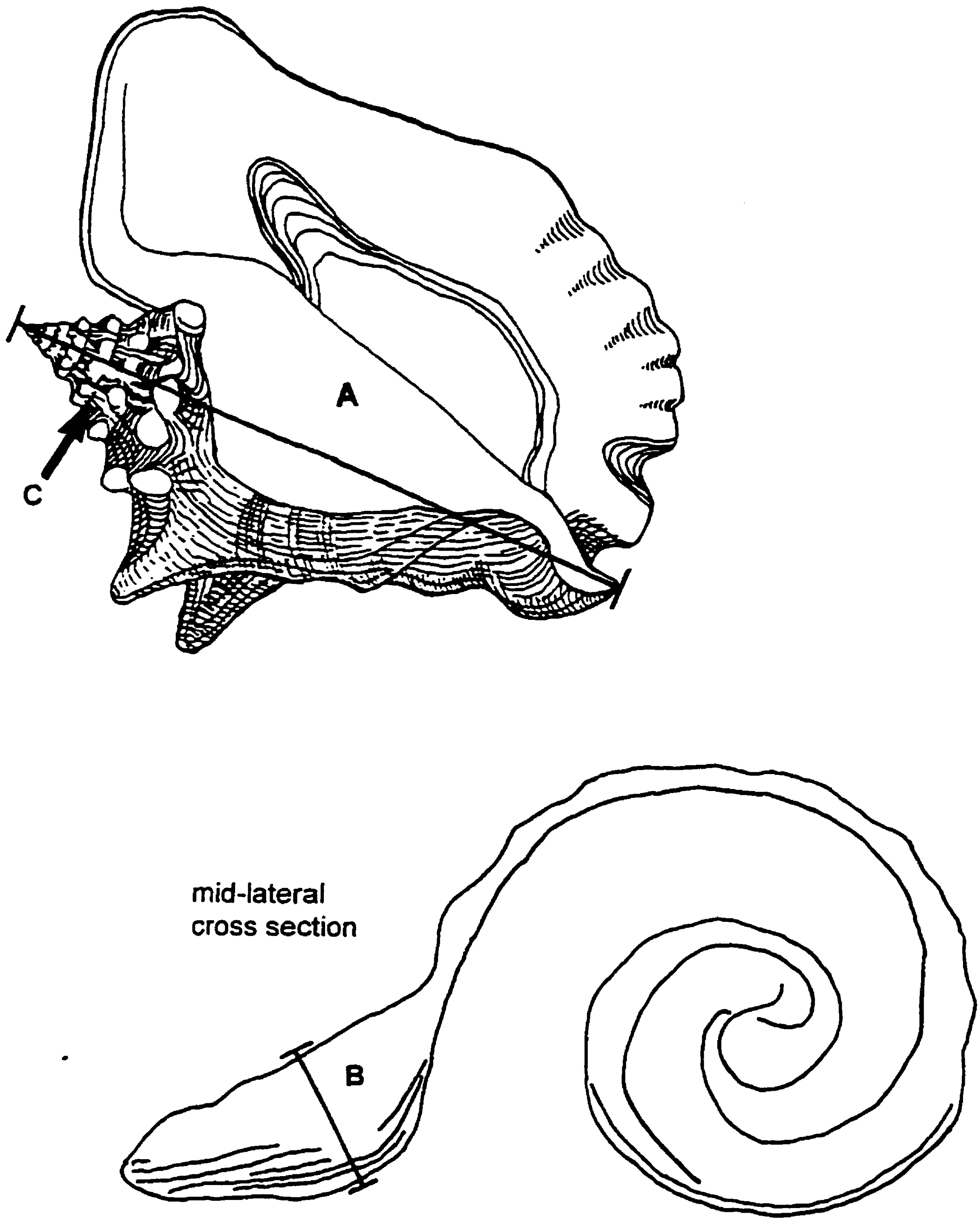

Figure 2. Morphometric measurements of shell length, A (tip of spire to sphonal canal), shell lip thickness, B, and point of "knocking", C, (4th whorl of spire) of *Strombus gigas*.

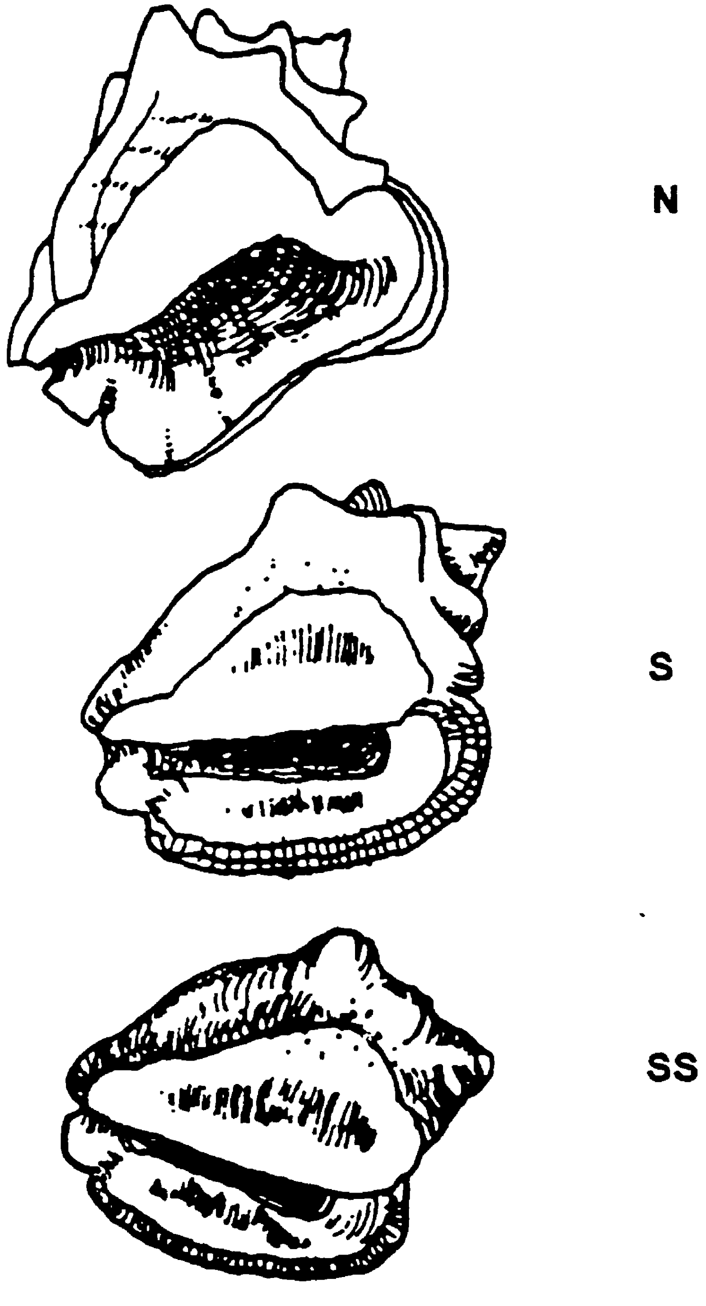

Figure 3. Erosion categories ((N=normal, S=stoned, SS=severly stoned) used for adult conch collected on Pedro Bank (adapted from Orr: K. 1988. The life story of the queen conch. Marine Biological Laboratory, Woods Hole, Mass.)

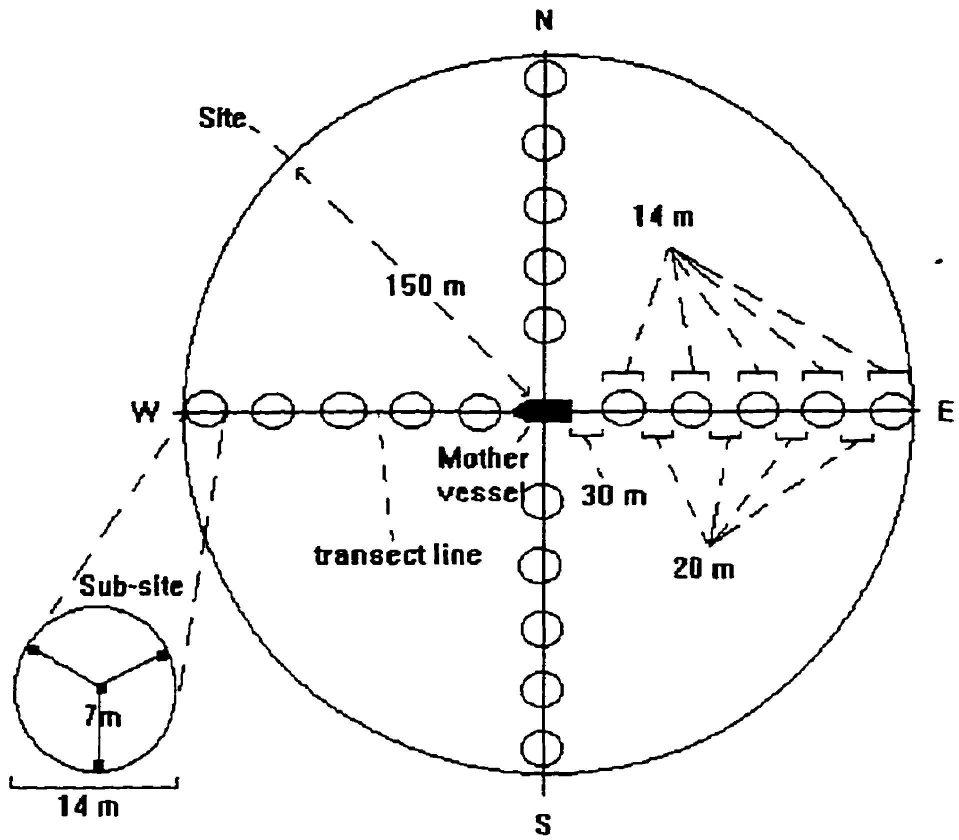

Figure 4. Abundance survey sampling method used during the November 1994 survey on Pedro Bank.

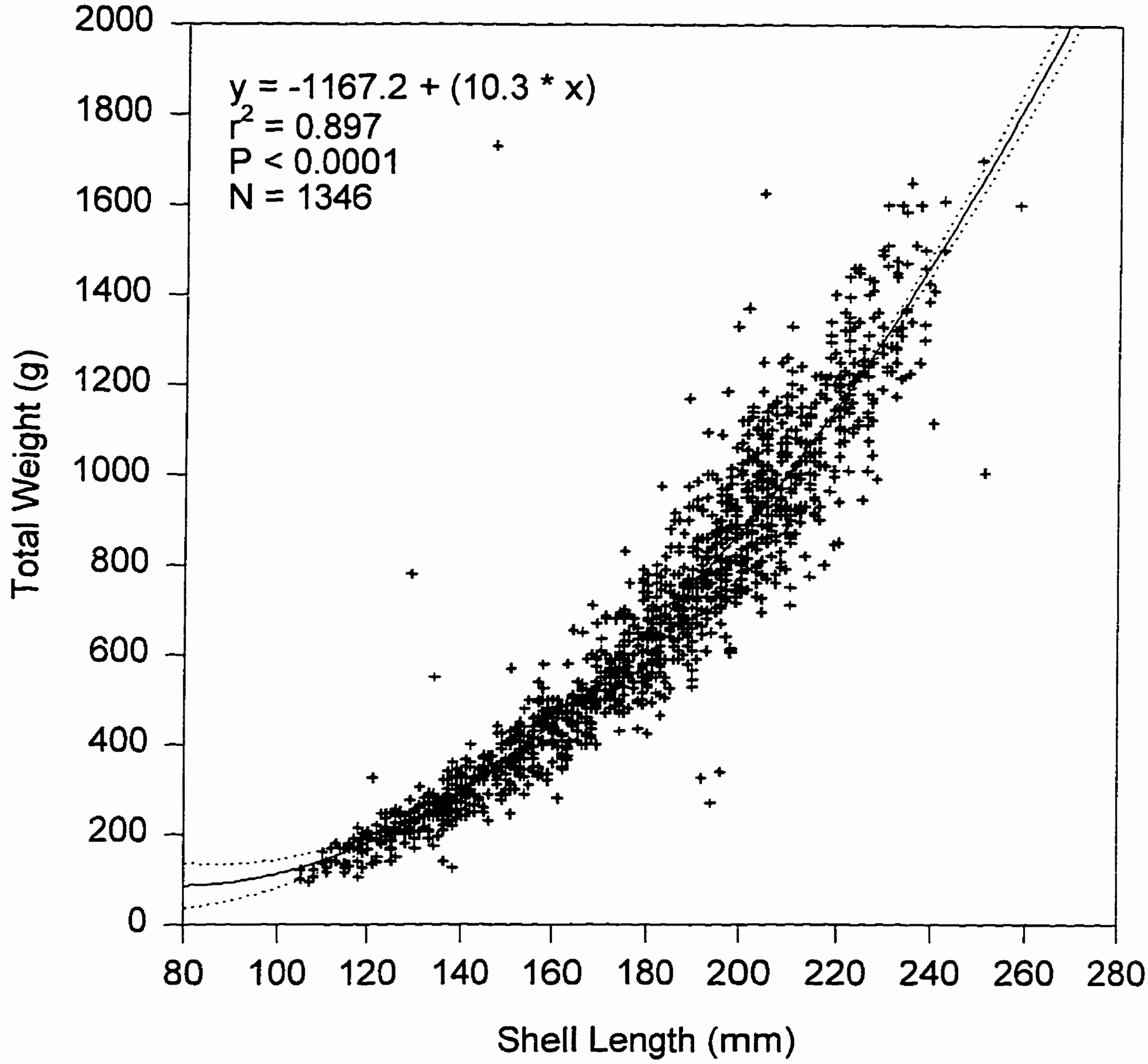

Figure 5. Shell length vs. total weight of all juvenile conch collected at SW,DS, and JG on Pedro Bank during 1993-1994 (solid line is second order regression, dotted line is 95% confidence intervals)

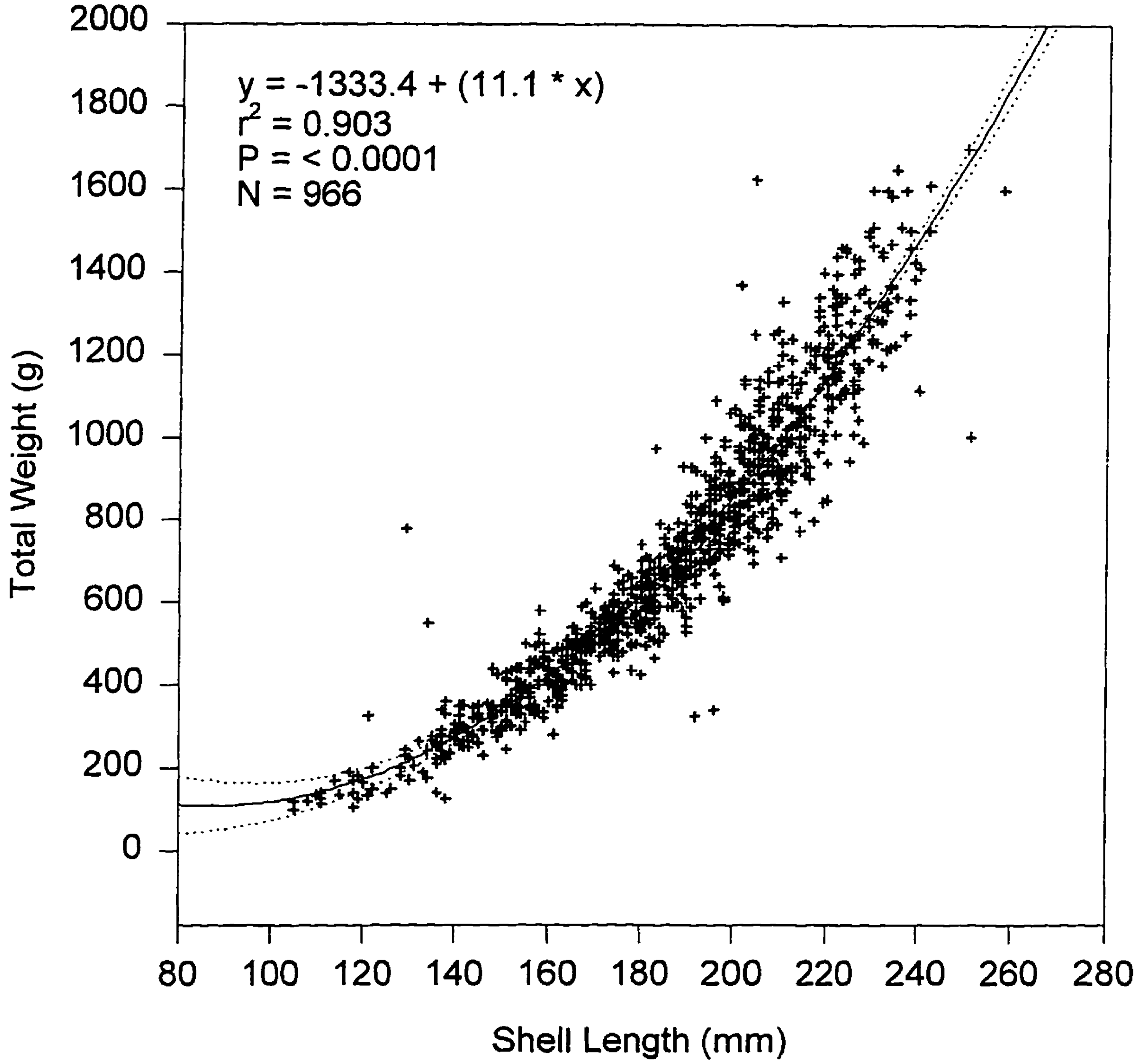

Figure 6. Shell length vs. total weight of juvenile conch collected at SW on Pedro Bank during 1993-1994 (solid line second order regression, dotted line 95% confidence interval)

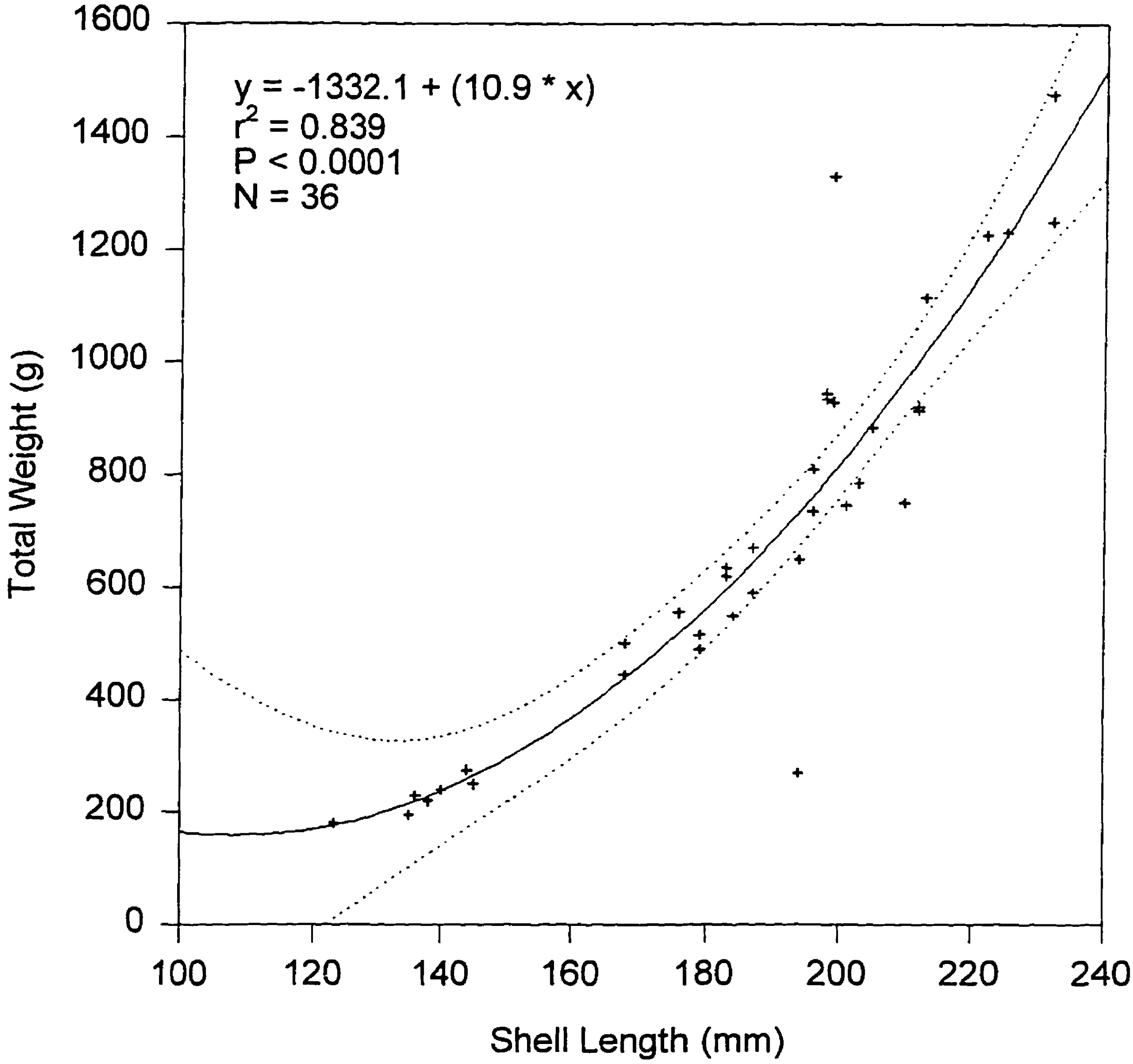

Figure 7. Shell length vs. total weight of juvenile conch collected at DS on Pedro bank during 1993-1994 (solid line second order regression, dotted line 95% confidence interval)

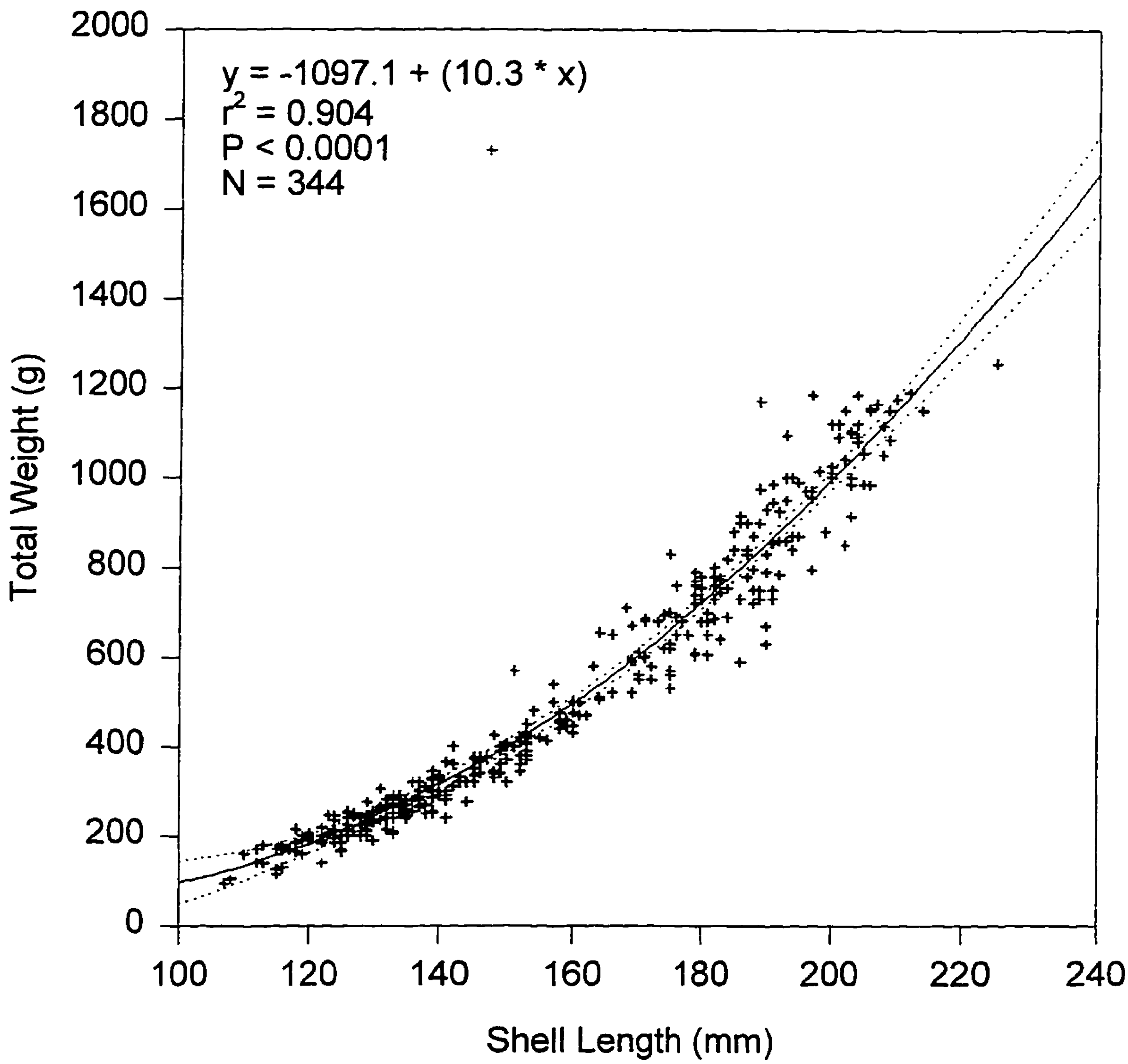

Figure 8. Shell length vs. total weight of juvenile conch collected at JG on Pedro Bank during 1993-1994 (solid line is second order regression, dotted line is 95% confidence interval)

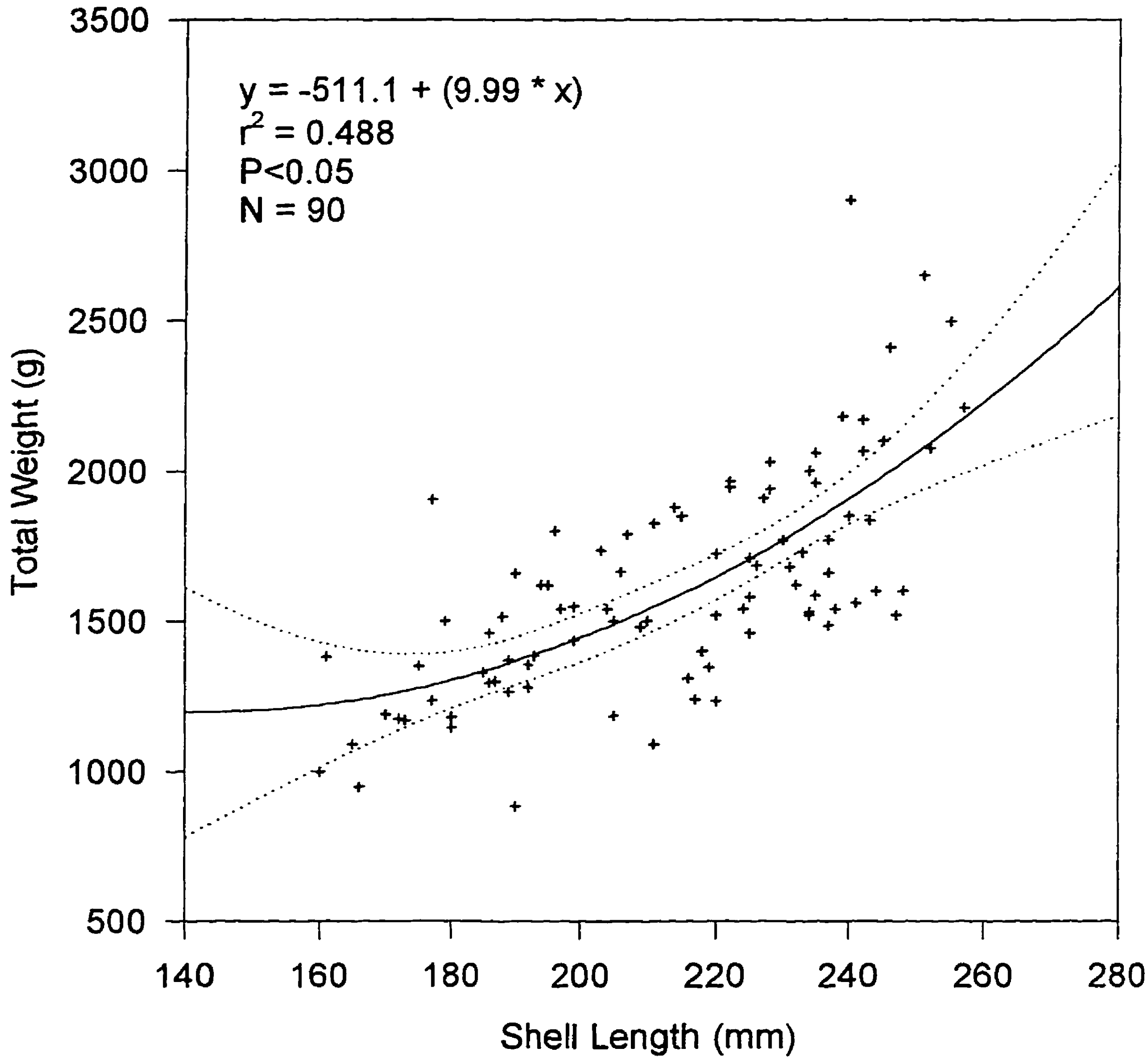

Figure 9. Shell length vs. total weight of adult conch collected at SW on Pedro Bank during 1993-1994 (solid line second order regression, dotted line 95% confidence interval)

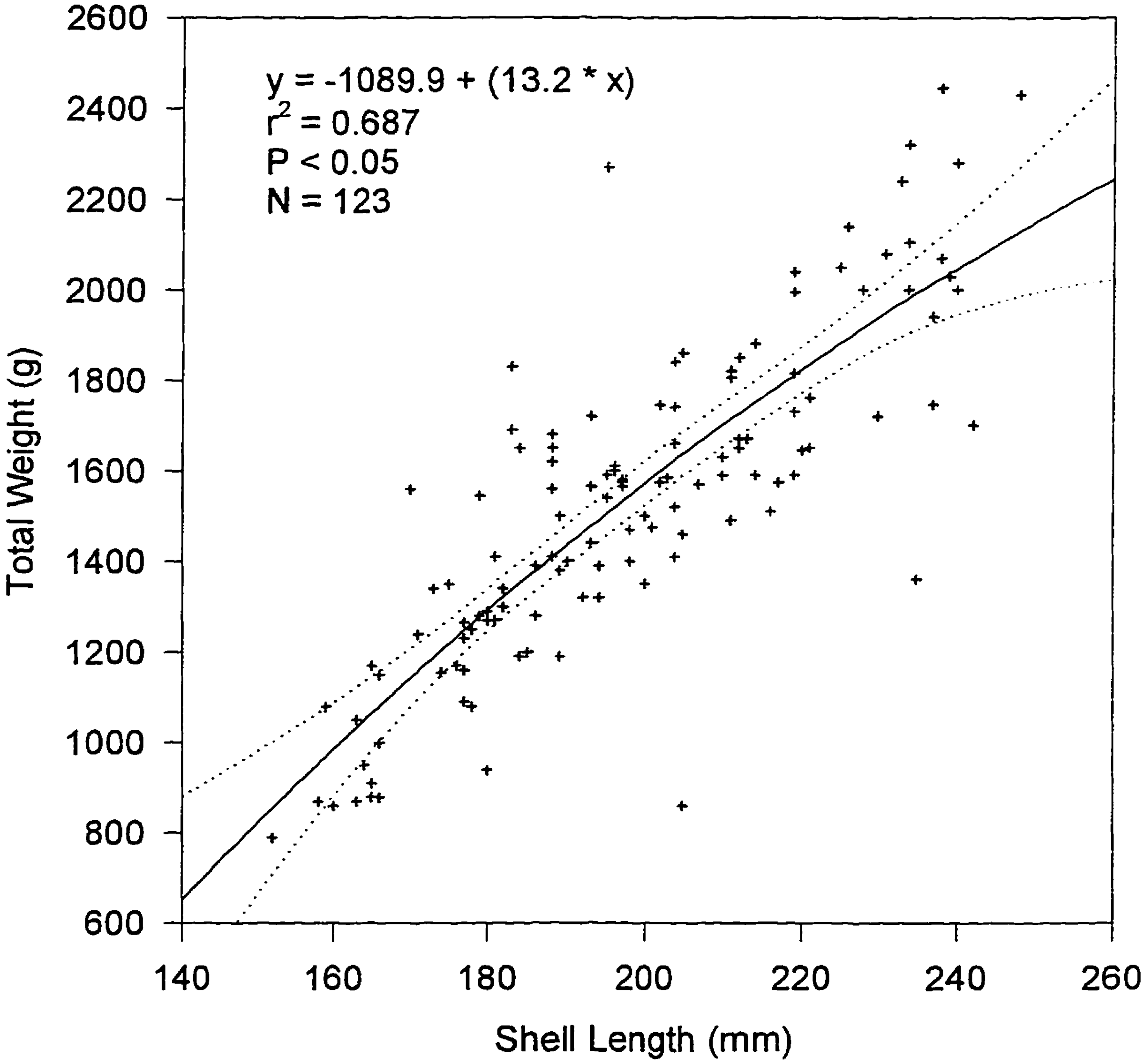

Figure 10. Shell length vs. total weight of adult conch collected at DS on Pedro Bank during 1993-1994 (solid line second order regression, dotted line 95% confidence interval)

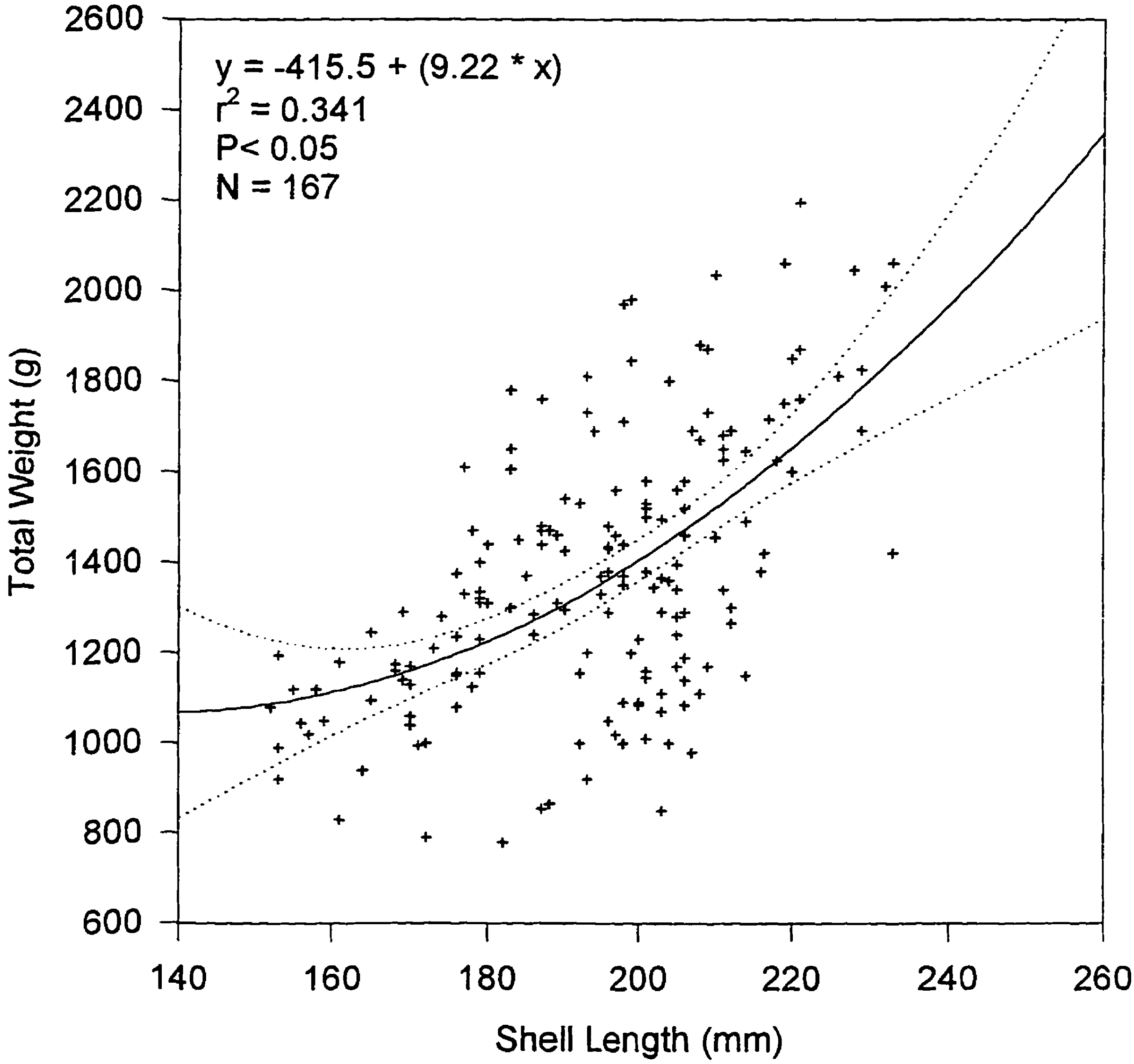

Figure 11. Shell length vs. total weight of adult conch collected at JG on Pedo Bank during 1993-1994 (solid line second order regression, dotted line 95% confidence interval)

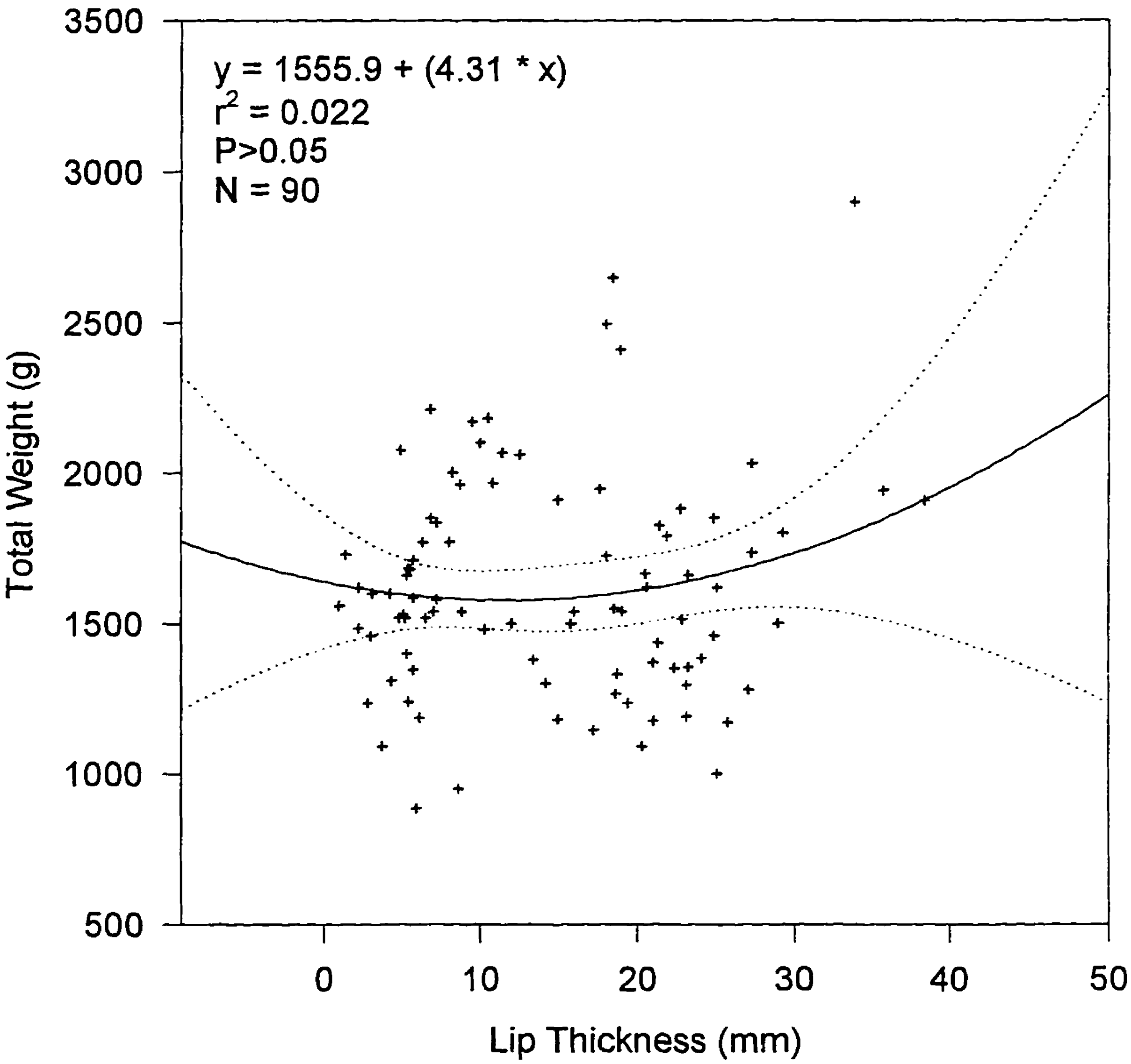

Figure 12. Shell lip thickness vs. total weight of adult conch collected at SW on Pedro Bank during 1993-1994 (solid line second order regression, dotted line 95% confidence interval)

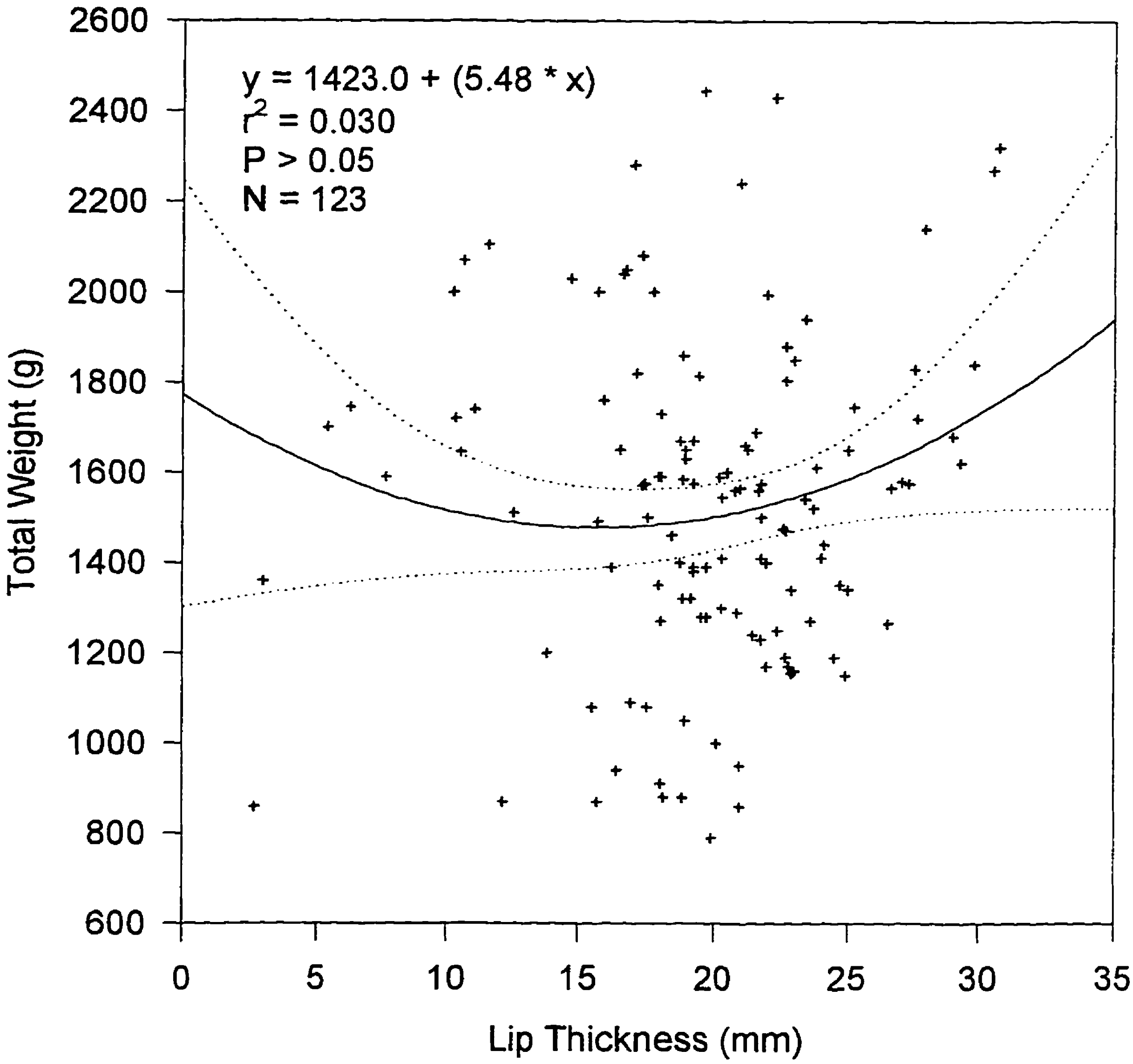

Figure 13. Shell lip thickness vs. total weight of adult conch collected at DS on Pedro Bank during 1993-1994 (solid line second order regression, dotted line 95% confidence interval)

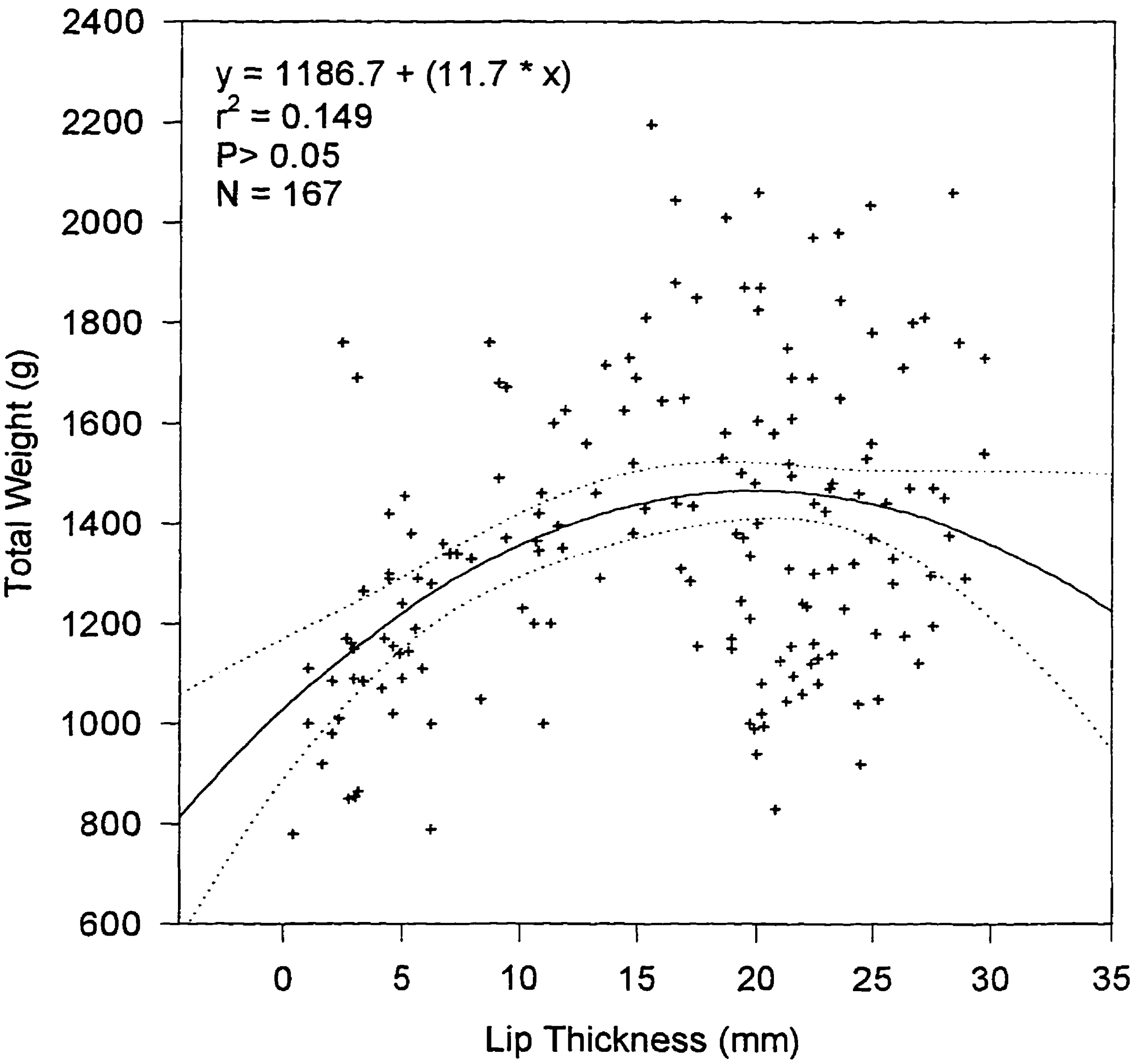

Figure 14. Shell lip thickness vs. total weight of adult conch collected at JG on Pedro Bank during 1993-1994 (solid line second order regression, dotted line 95% confidence interval)

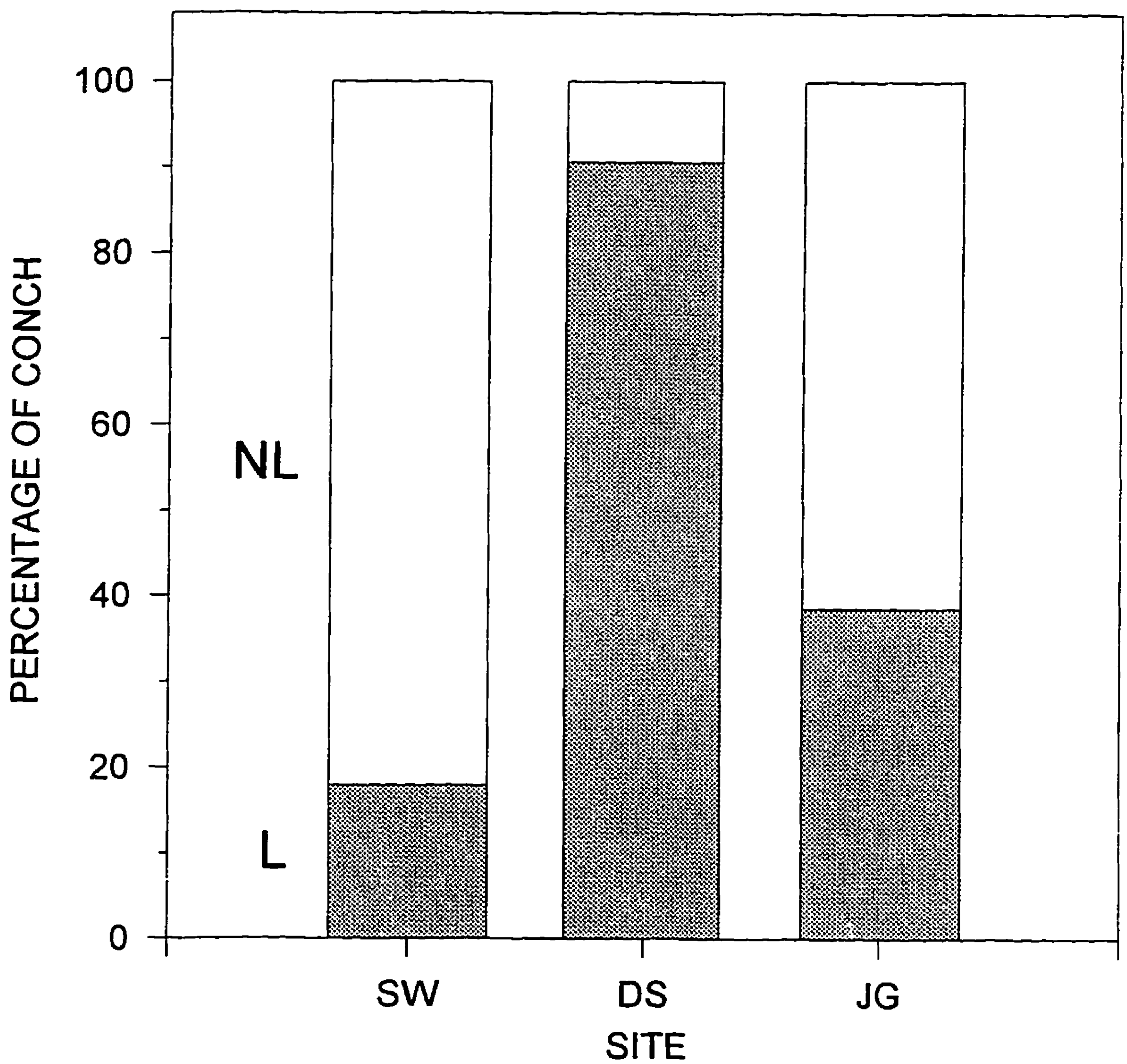

Figure 15. Percent frequency of lipped (L, adult & sub-adult) to non-lipped (NL, juvenile) conch at three sites (SW, N=1176; DS, N=384; JG, N=559) on Pedro Bank during 1993-1994.

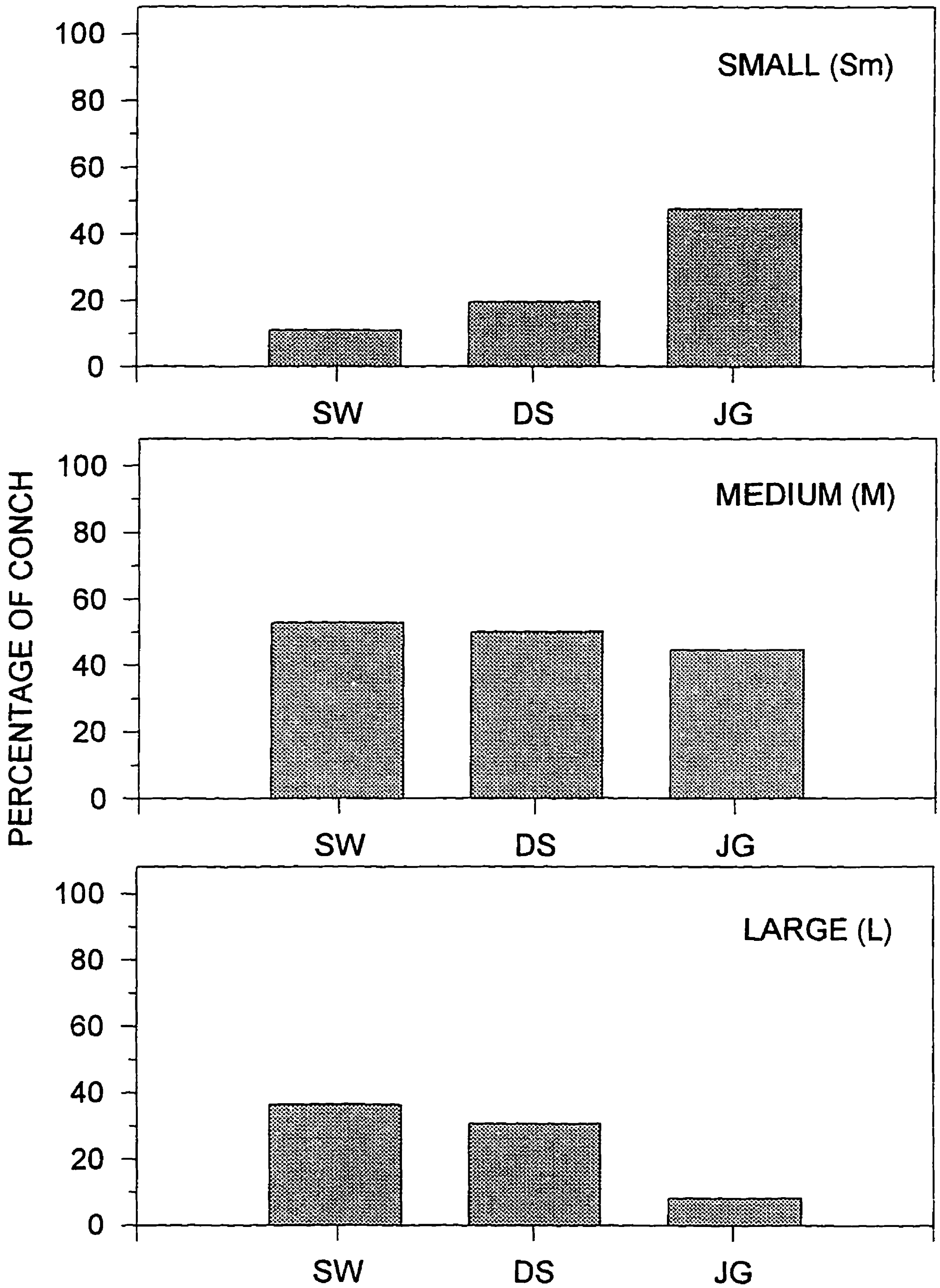

Figure 16. Percent frequency of non-lipped (juvenile) conch by length classes (Sm, M,L) at three sites (SW, N=966; DS, N=36; JG, N=344) on Pedro Bank during 1993-1994.

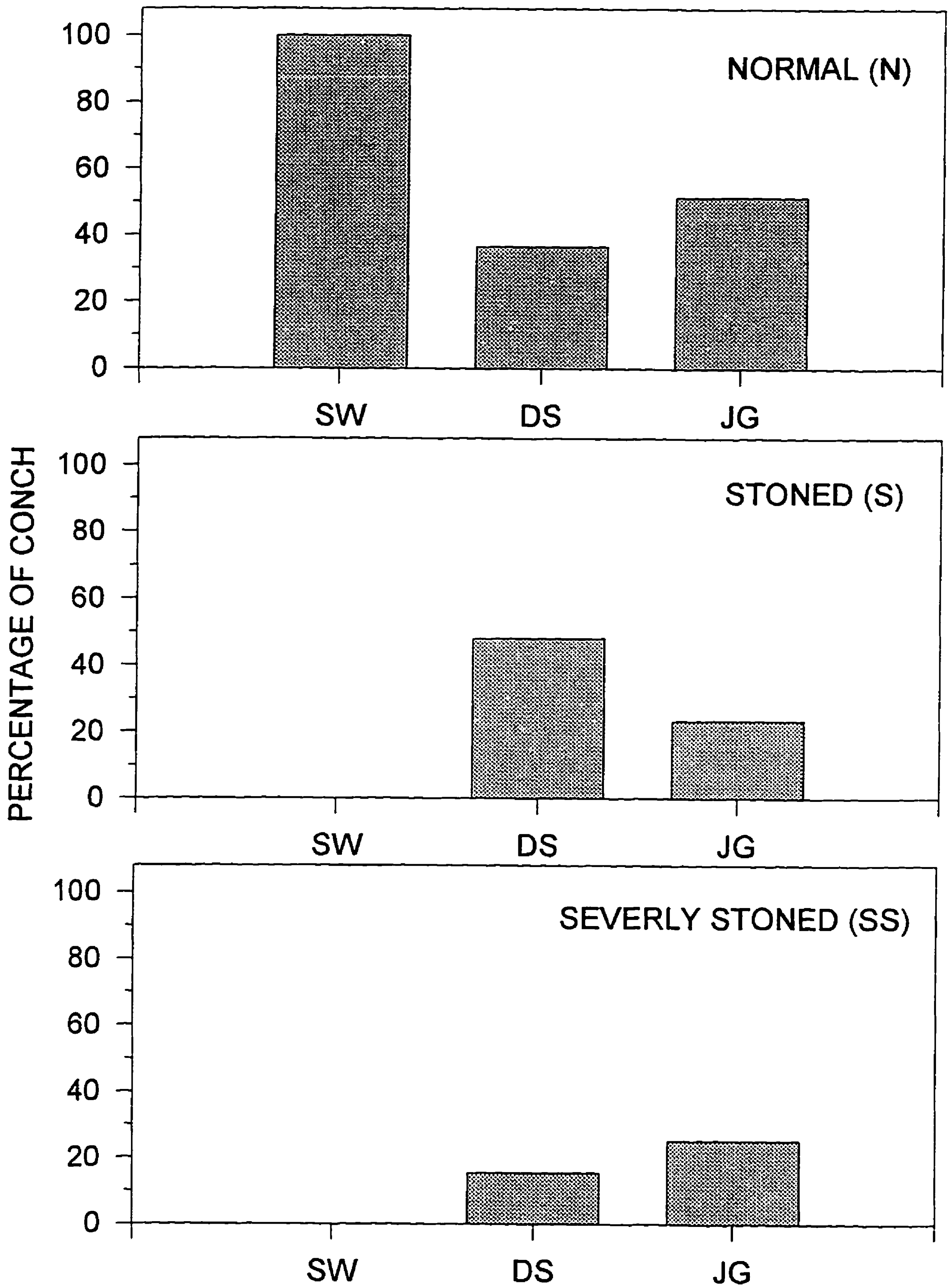

Figure 17. Percent frequency of adult conch by erosion category (N,S,SS) at three sites (SW, N=51; DS, N=123; JG, N=167) on Pedro Bank during 1993-1994.

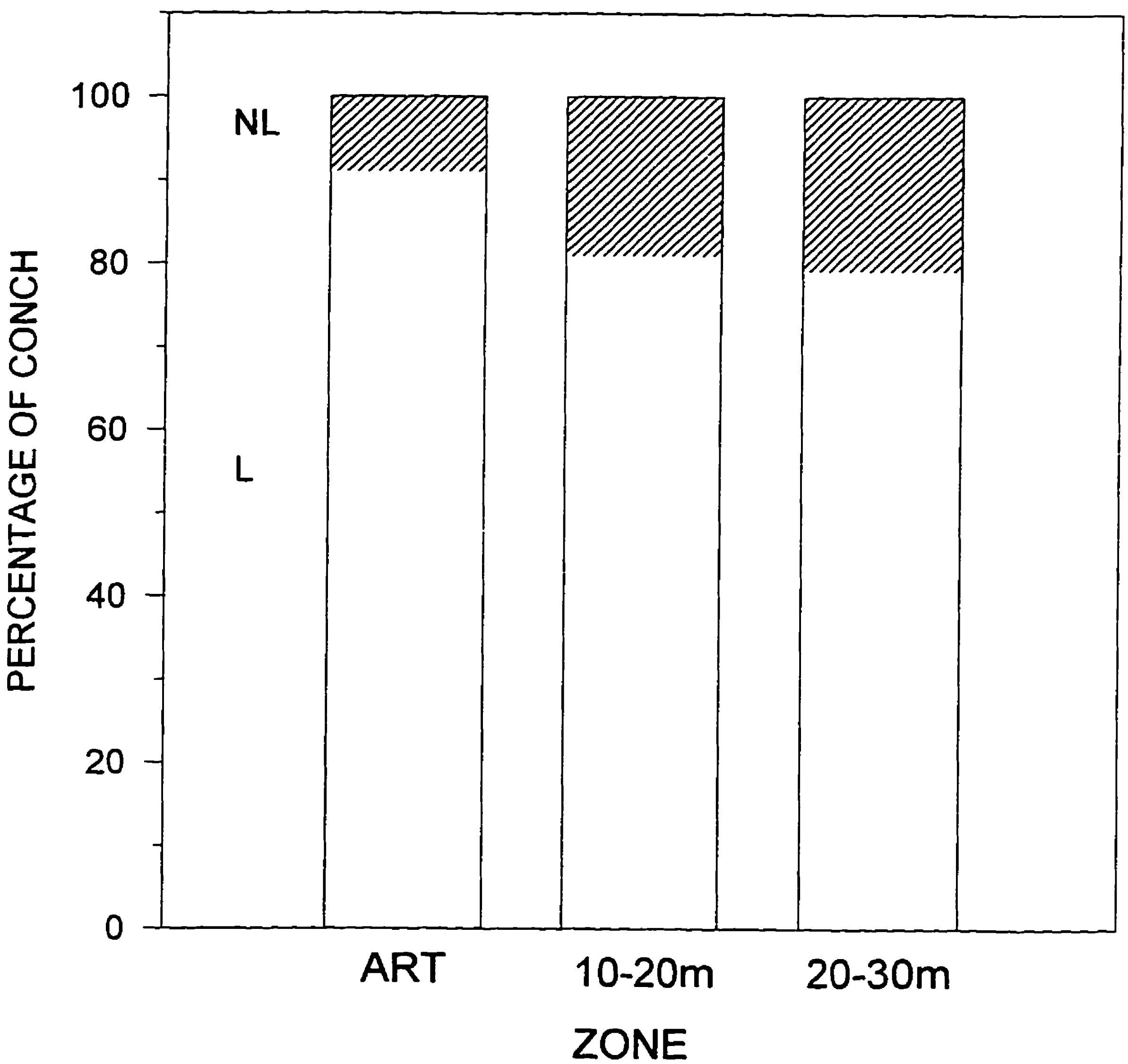

Figure 18. Percent frequency of lipped (L, adult & sub-adult) to non-lipped (NL, juvenile) conch collected in three zones (ART, N=192; 10-20m, N=2511; 20-30m, N=937) on Pedro Bank during November 1994 abundance survey.

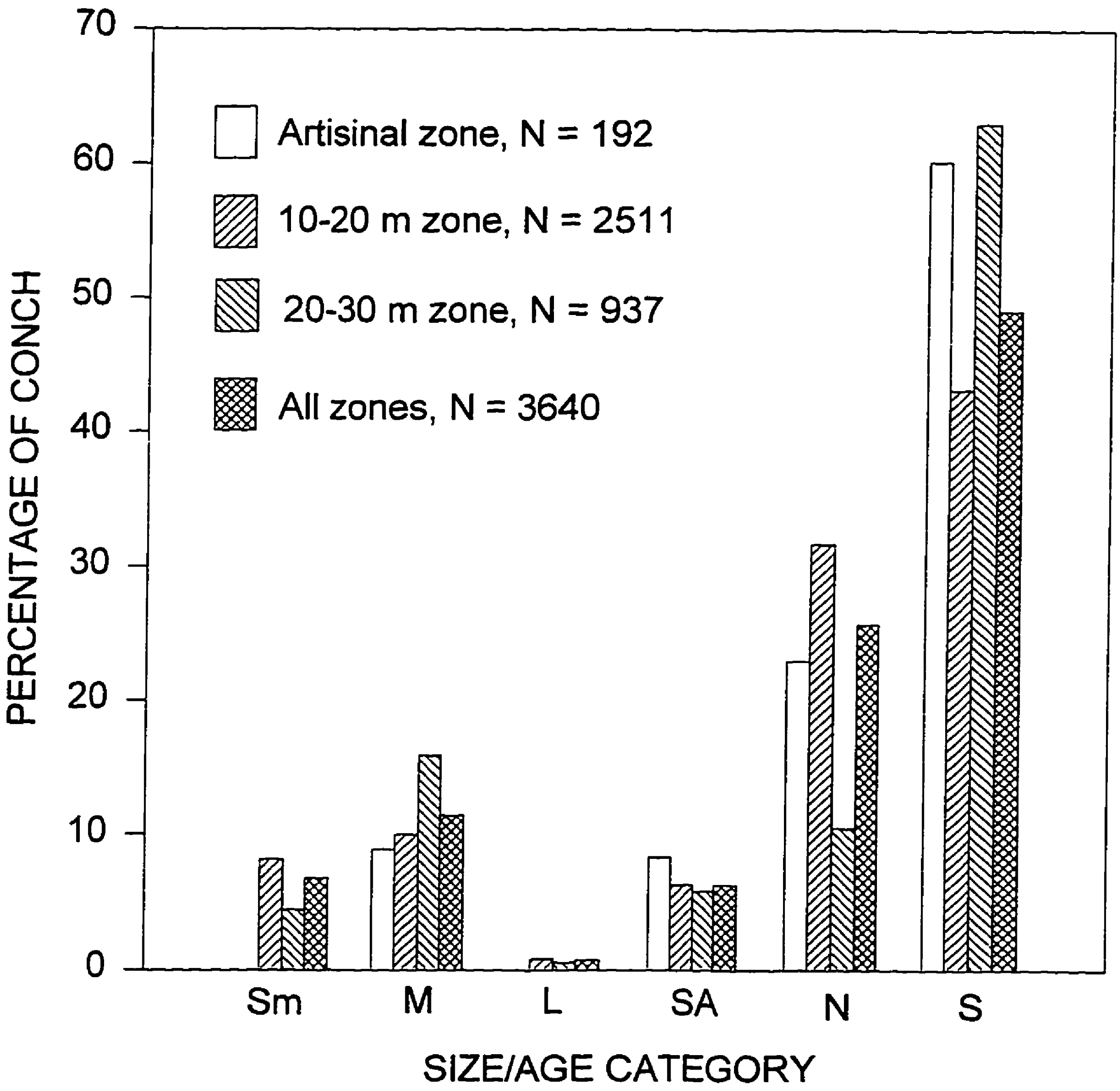

Figure 19. Distribution (%) of conch size/age categories (Sm,M,L, SA,N,S) collected in three zones (ART, 10-20m,20-30m) on the Pedro Bank during November 1994 abundance survey.

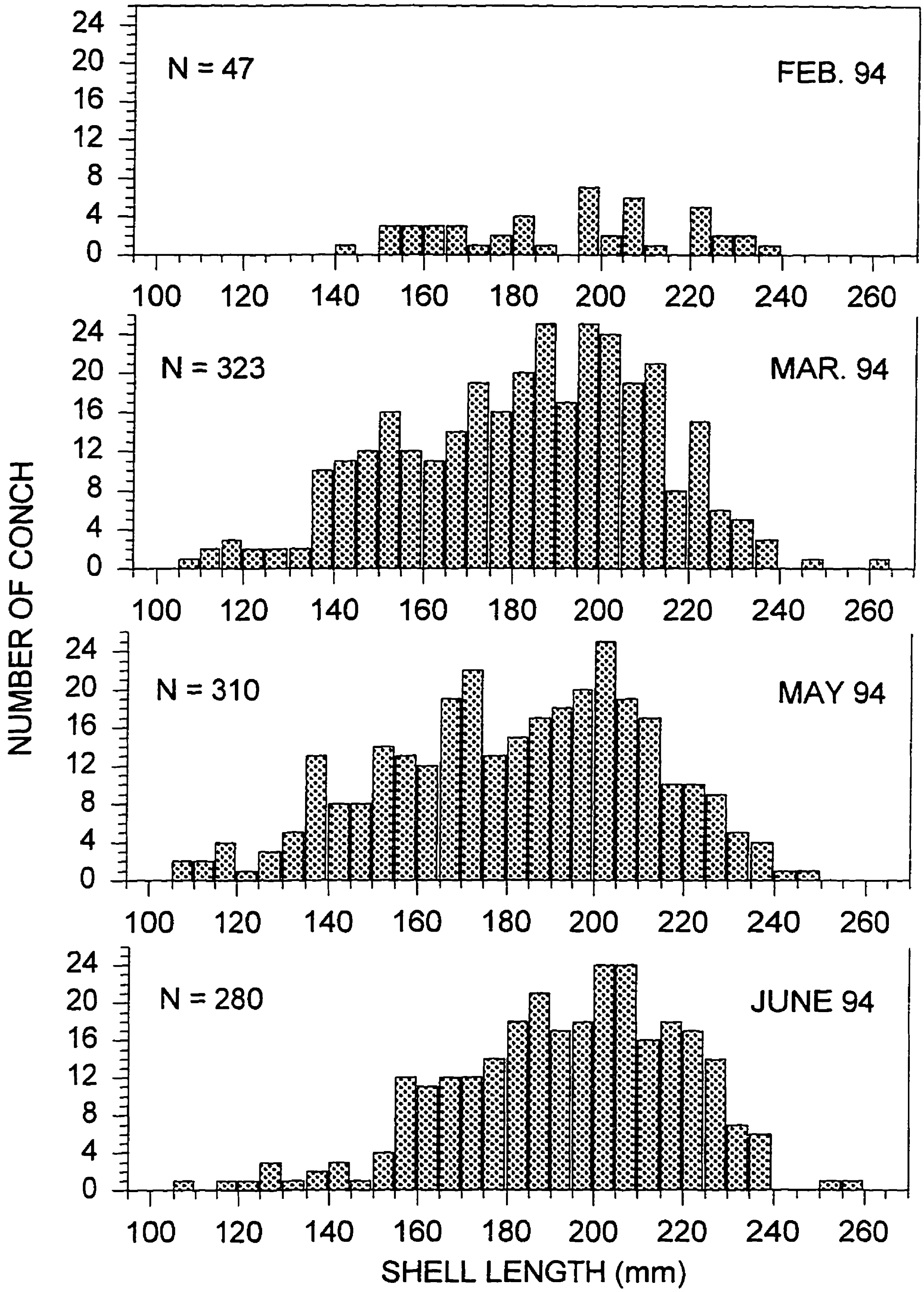

Figure 20. Shell length frequency distribution for non-lipped conch collected at SW during Feb., Mar., May, and June 1994.

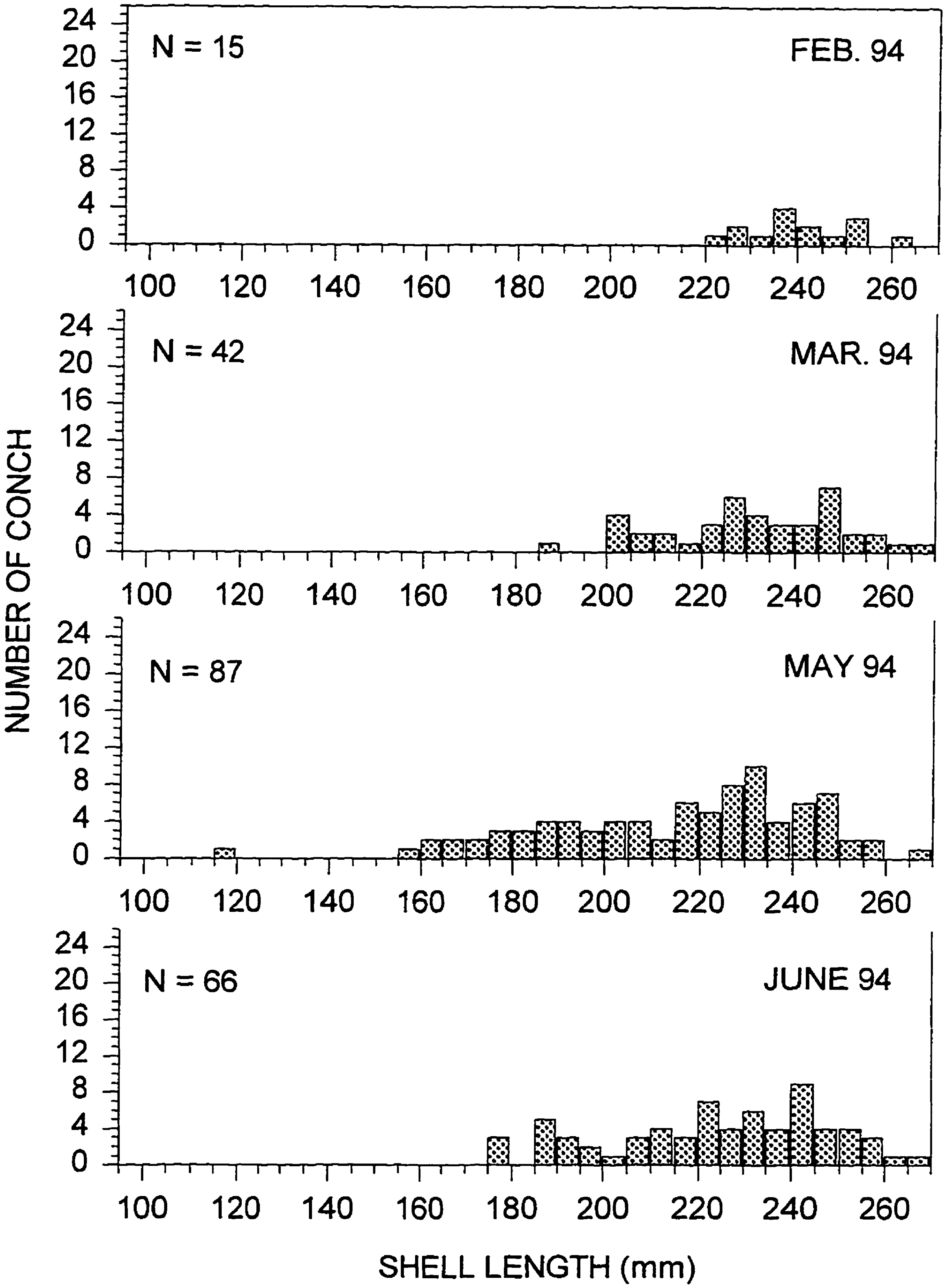

Figure 21. Shell length frequency distribution for lipped conch collected at SW during Feb., Mar., May, and June 1994

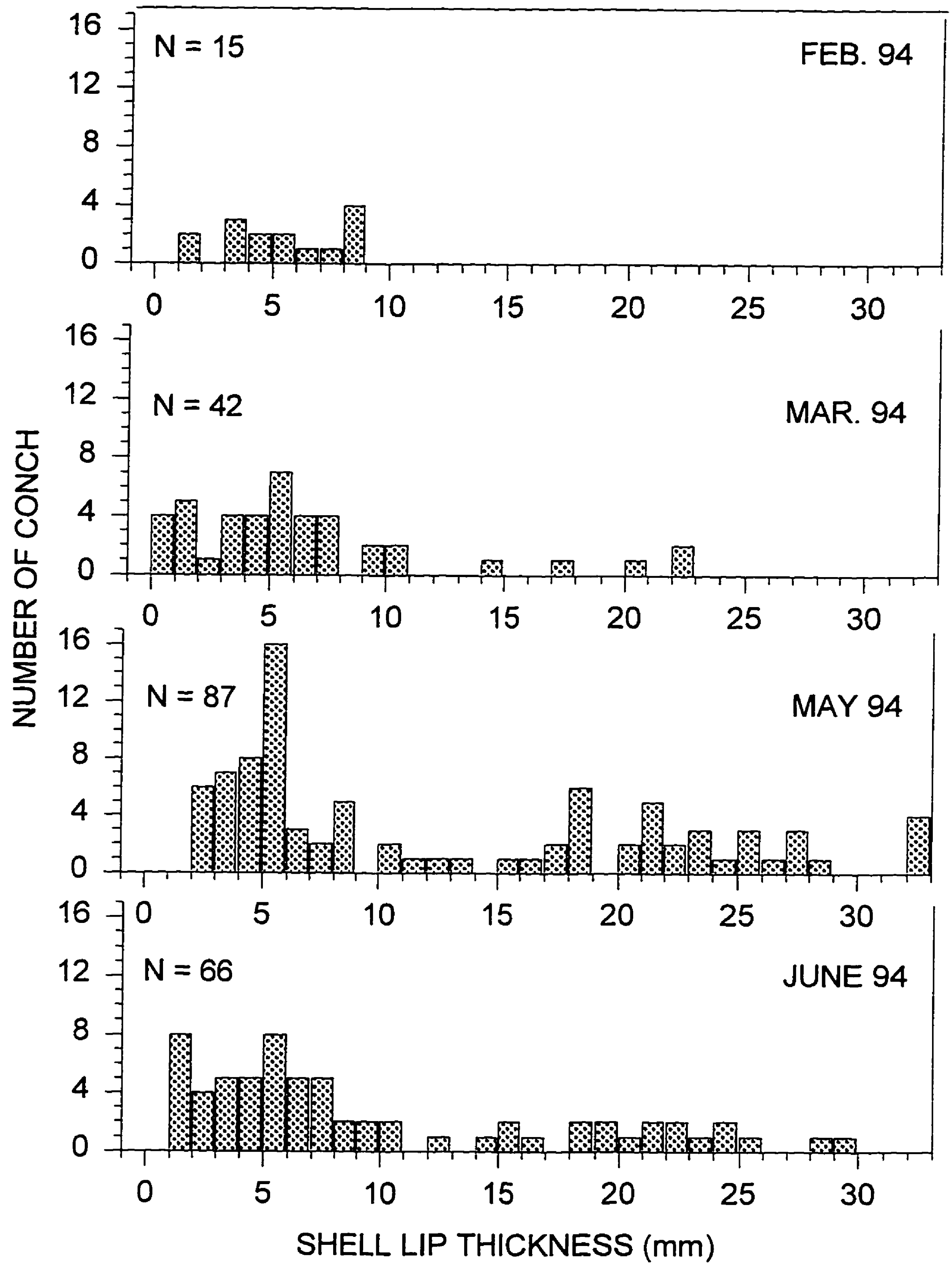

Figure 22. Shell lip thickness frequency distribution for conch collected at SW during Feb., Mar., May, and June 1994

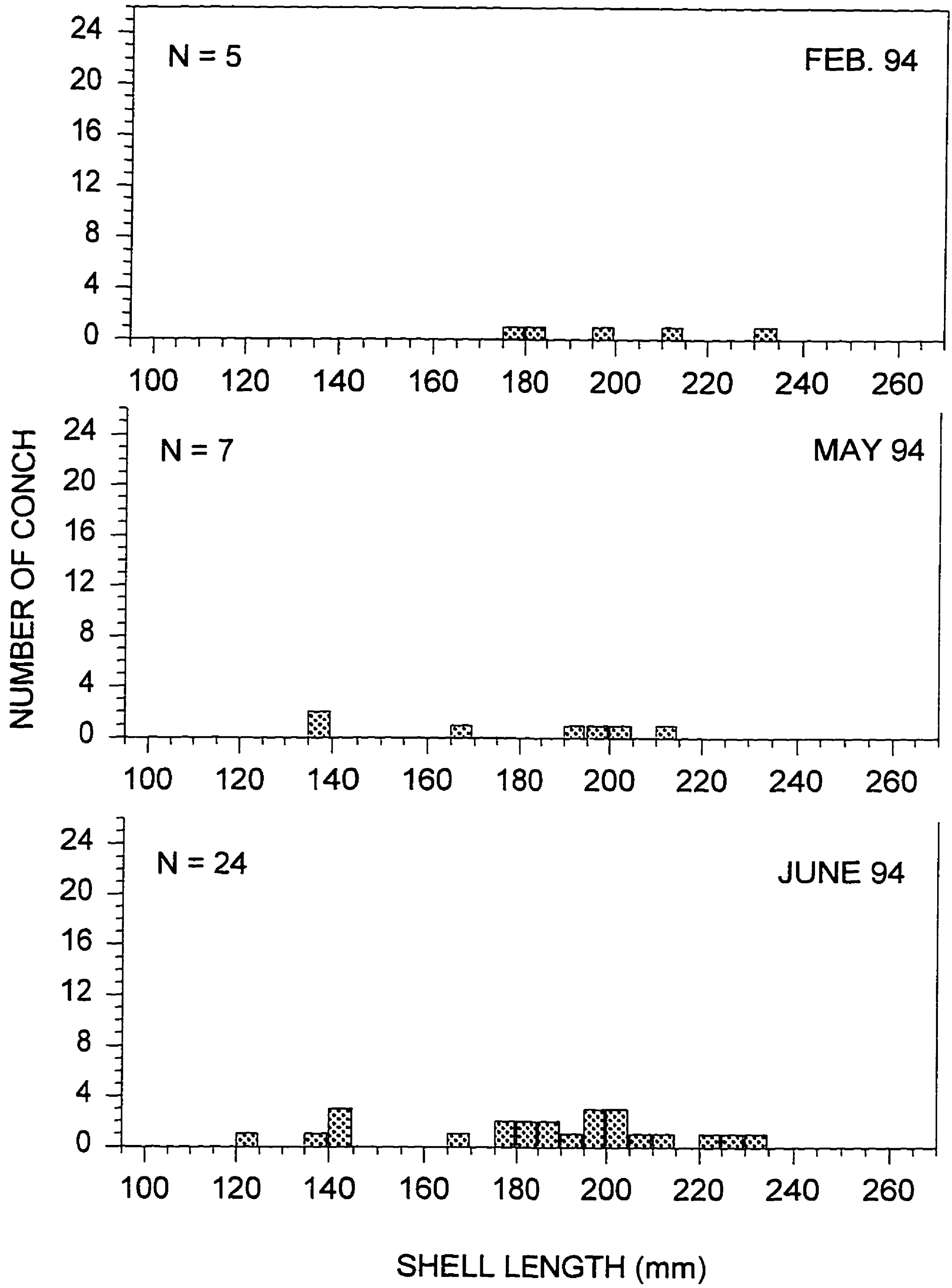

Figure 23. Shell length frequency distribution for non-lipped conch collected at DS during Feb., May, and June 1994.

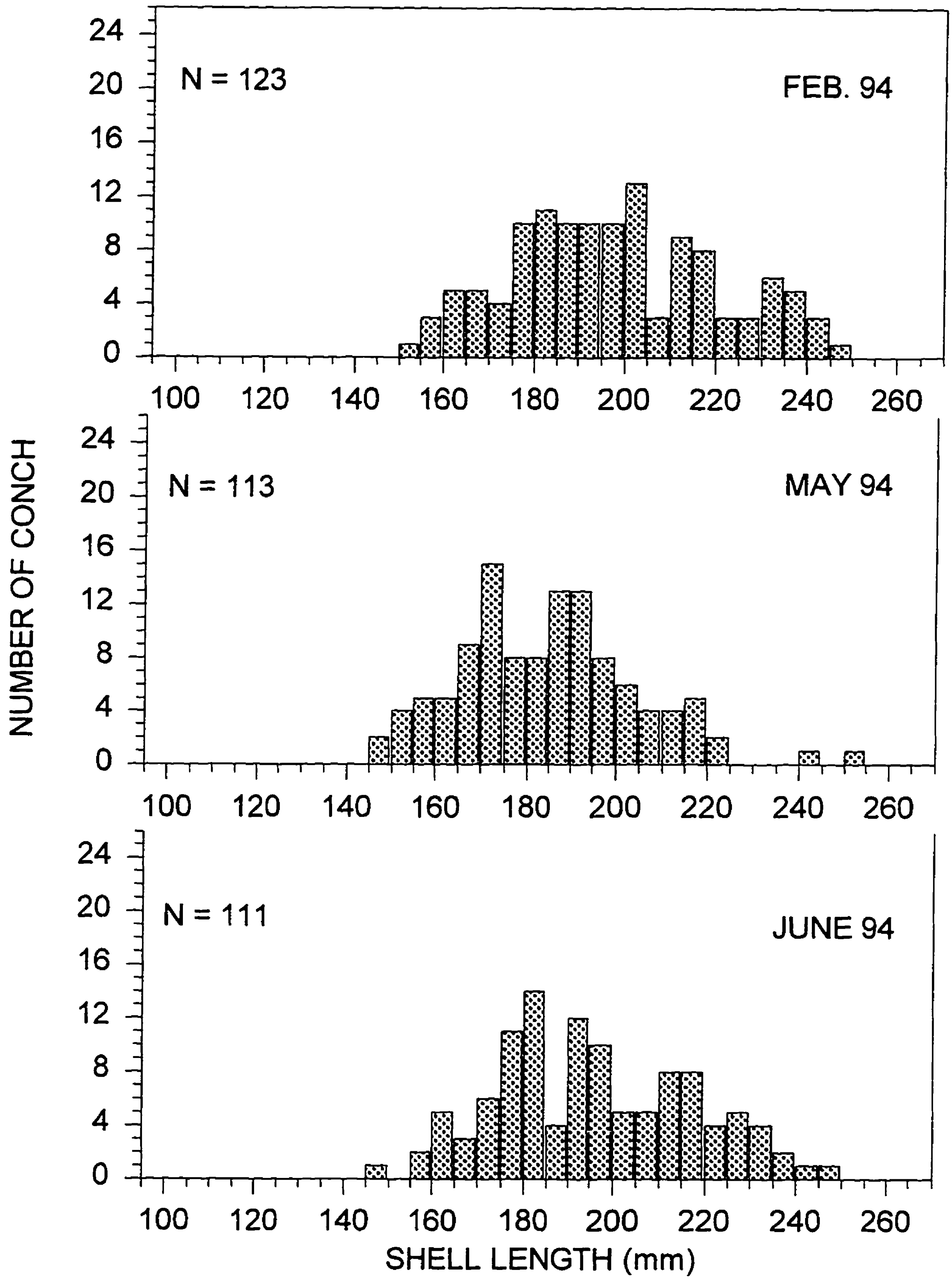

Figure 24. Shell length frequency distribution for lipped conch collected at DS during Feb., May, and June 1994.

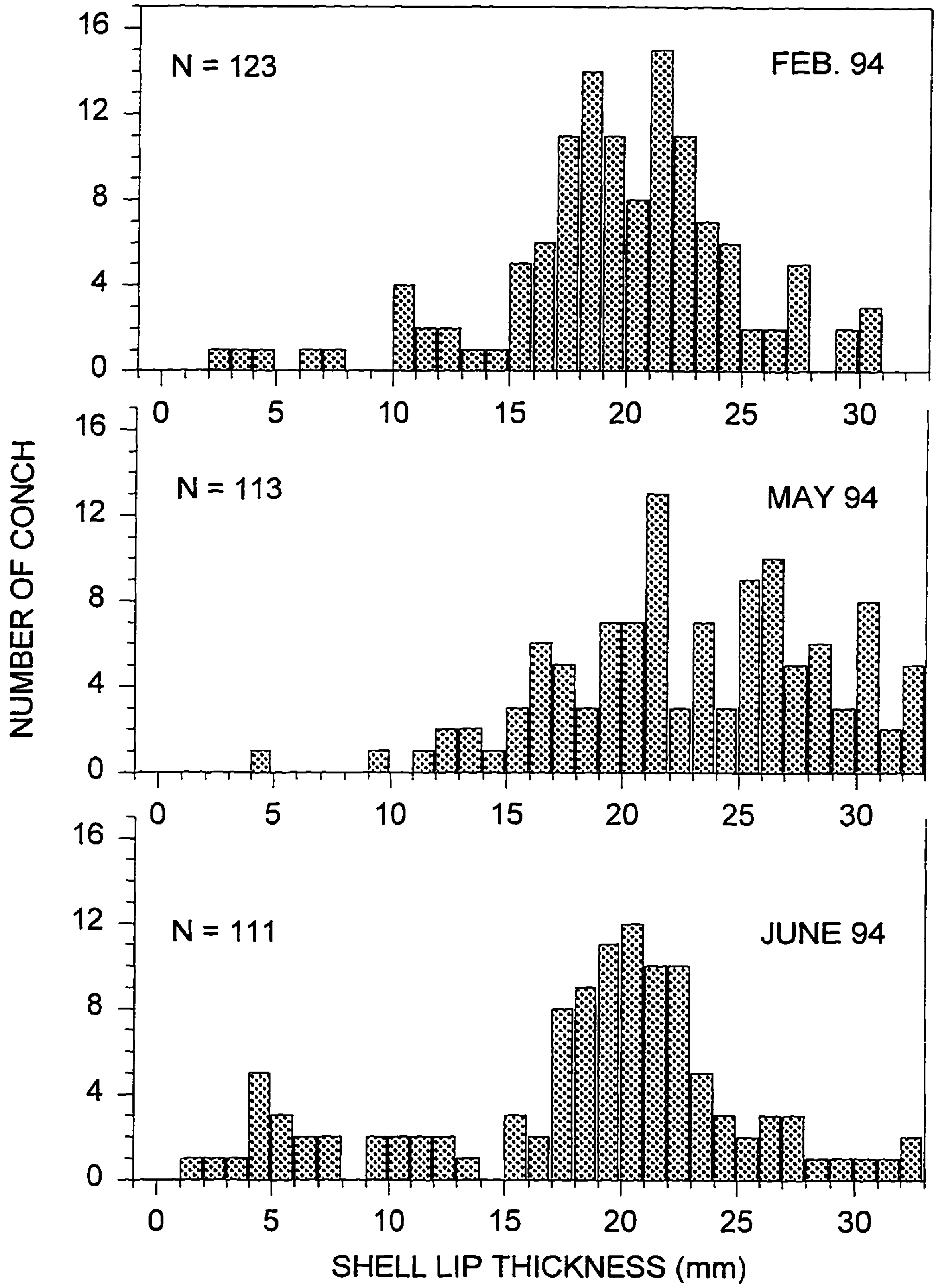

Figure 25. Shell lip thickness frequency distribution for conch collected at DS during Feb., May, and June 1994.

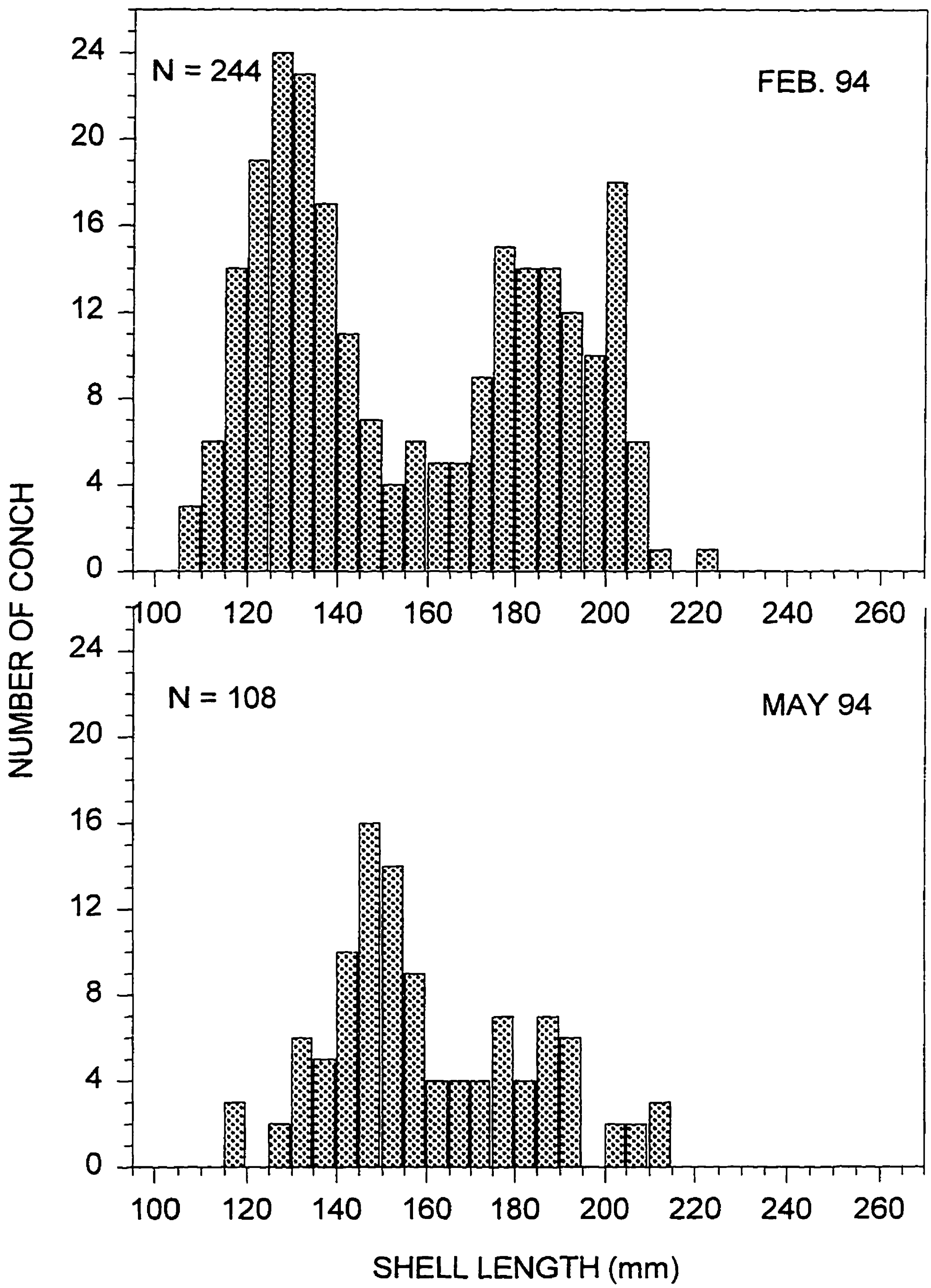

Figure 26. Shell length frequency distribution non-lipped conch collected at JG during Feb. and May 1994

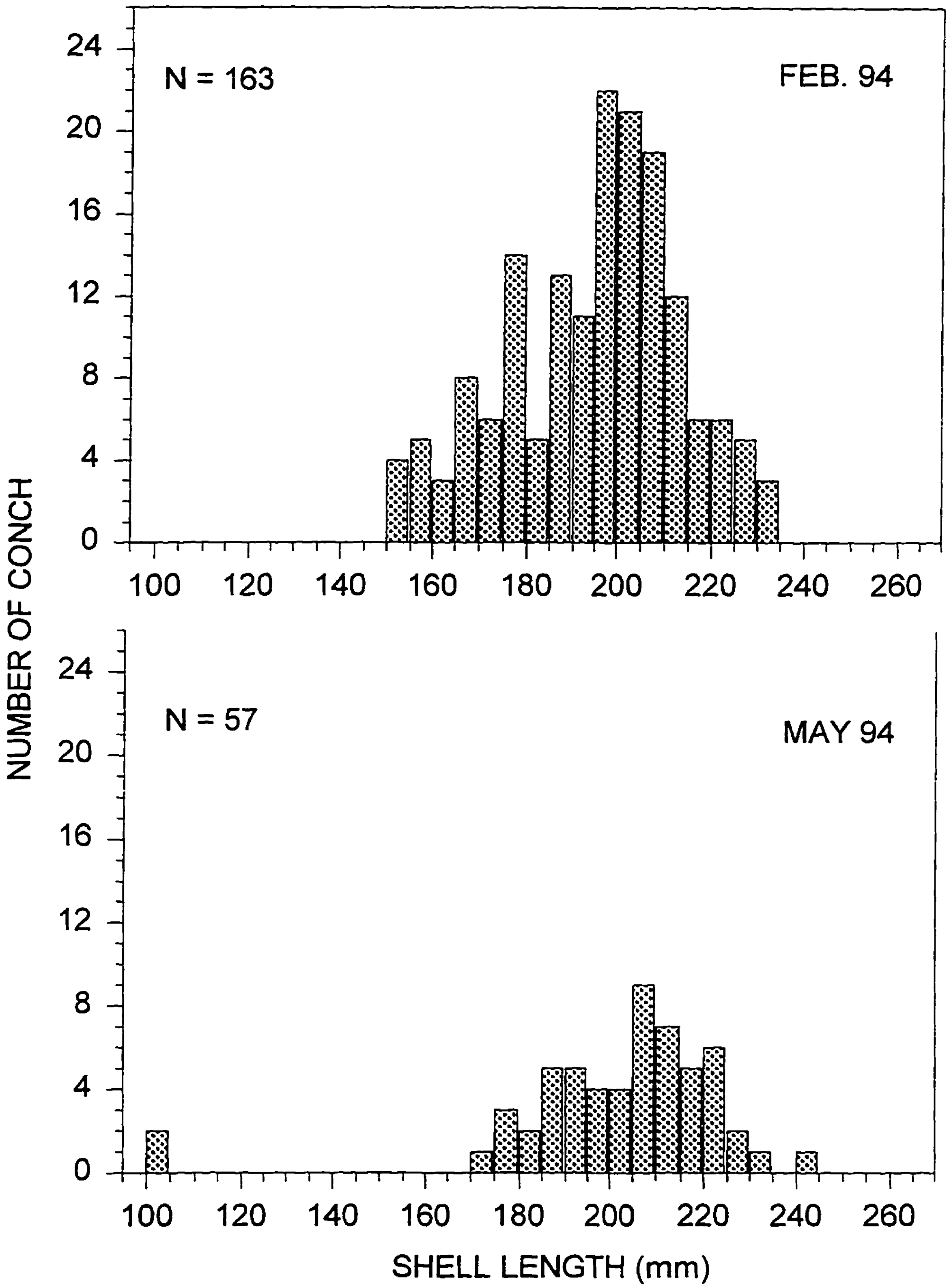

Figure 27. Shell length frequency distribution for lipped conch collected at JG during Feb. and May 1994

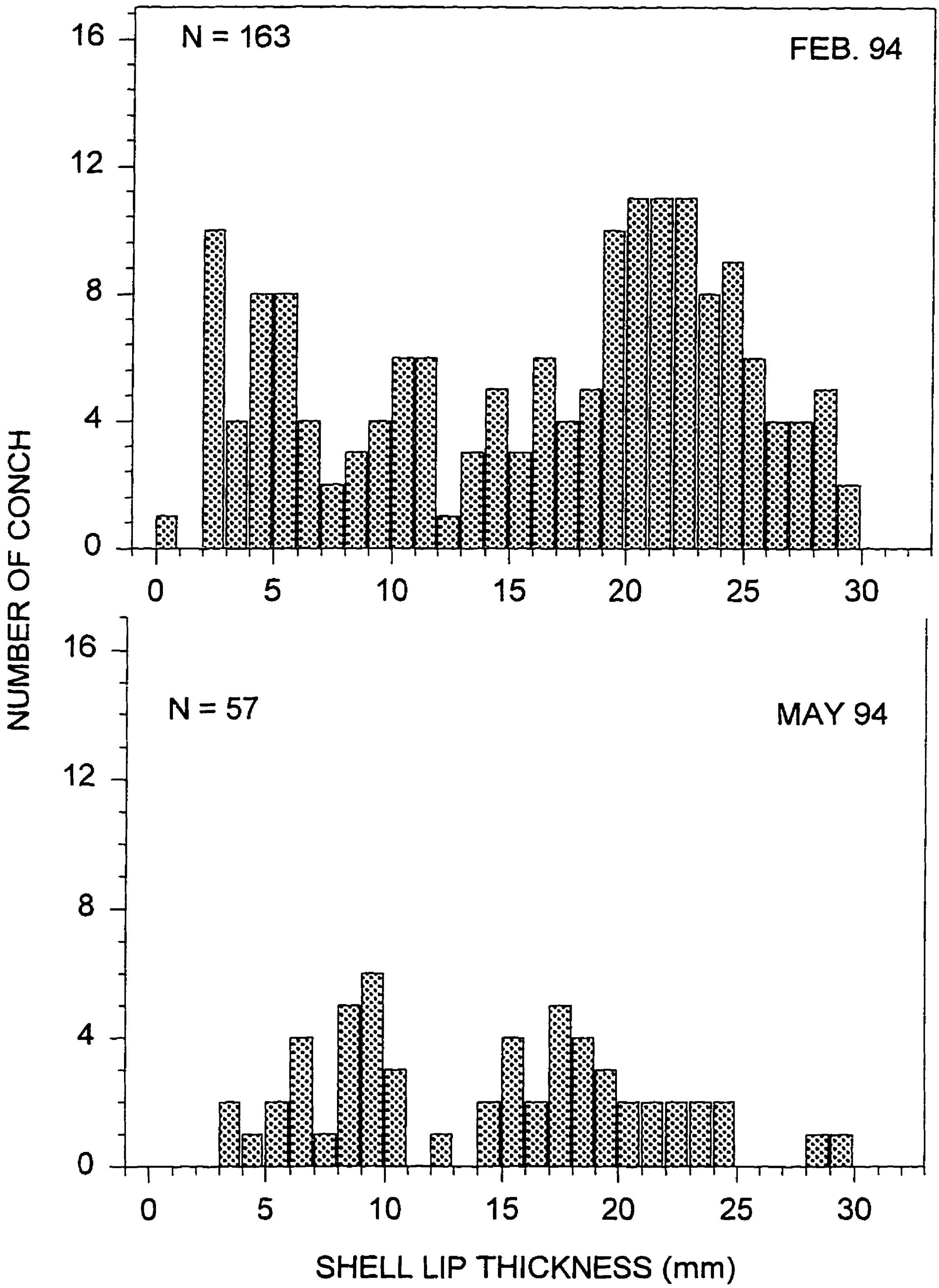

Figure 28. Shell lip thickness frequency distribution for conch collected at JG during Feb. and May 1994

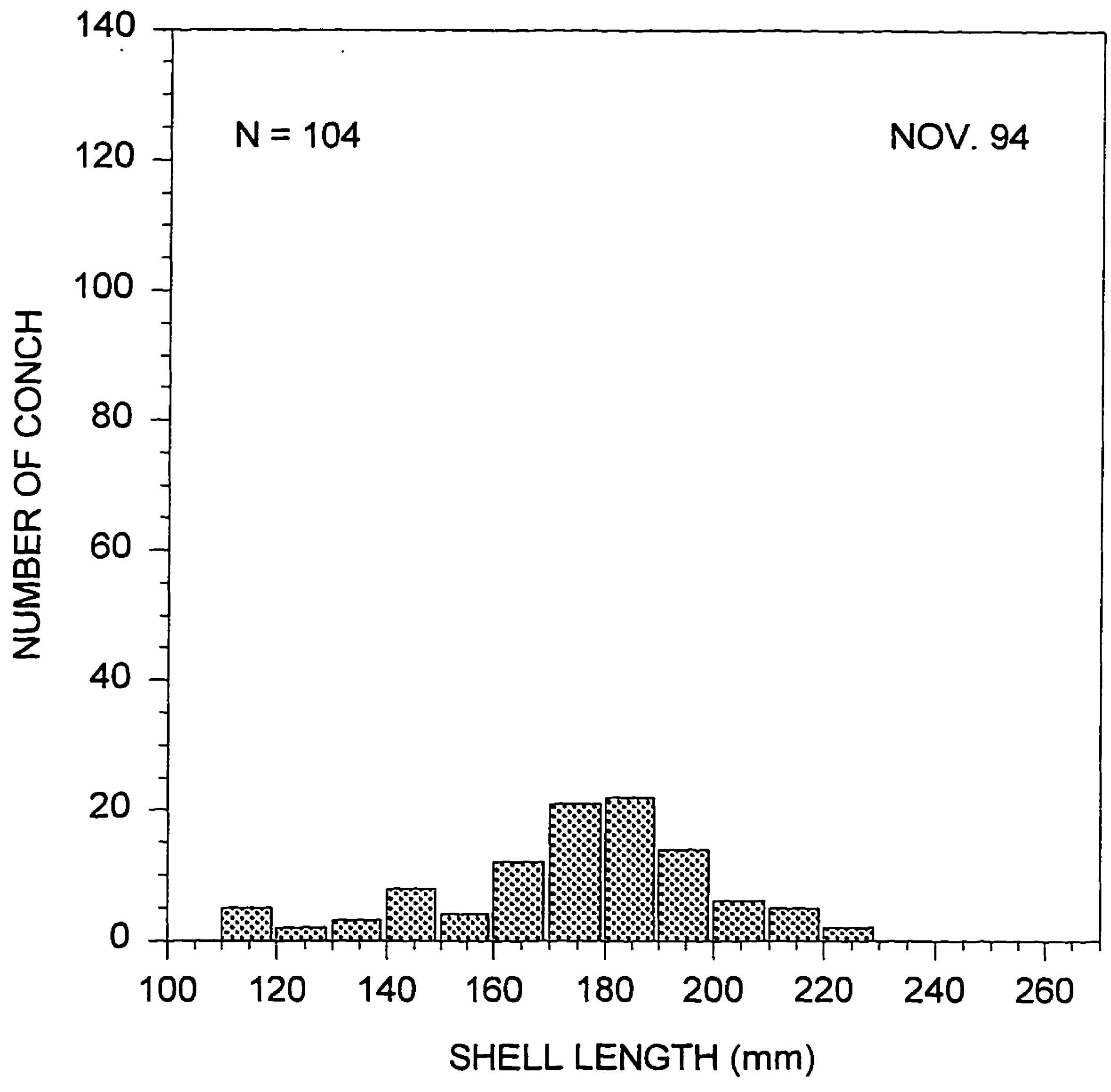

Figure 29. Shell length frequency distribution for non-lipped conch (juveniles) collected on Pedro Bank during November 1994 abundance survey.

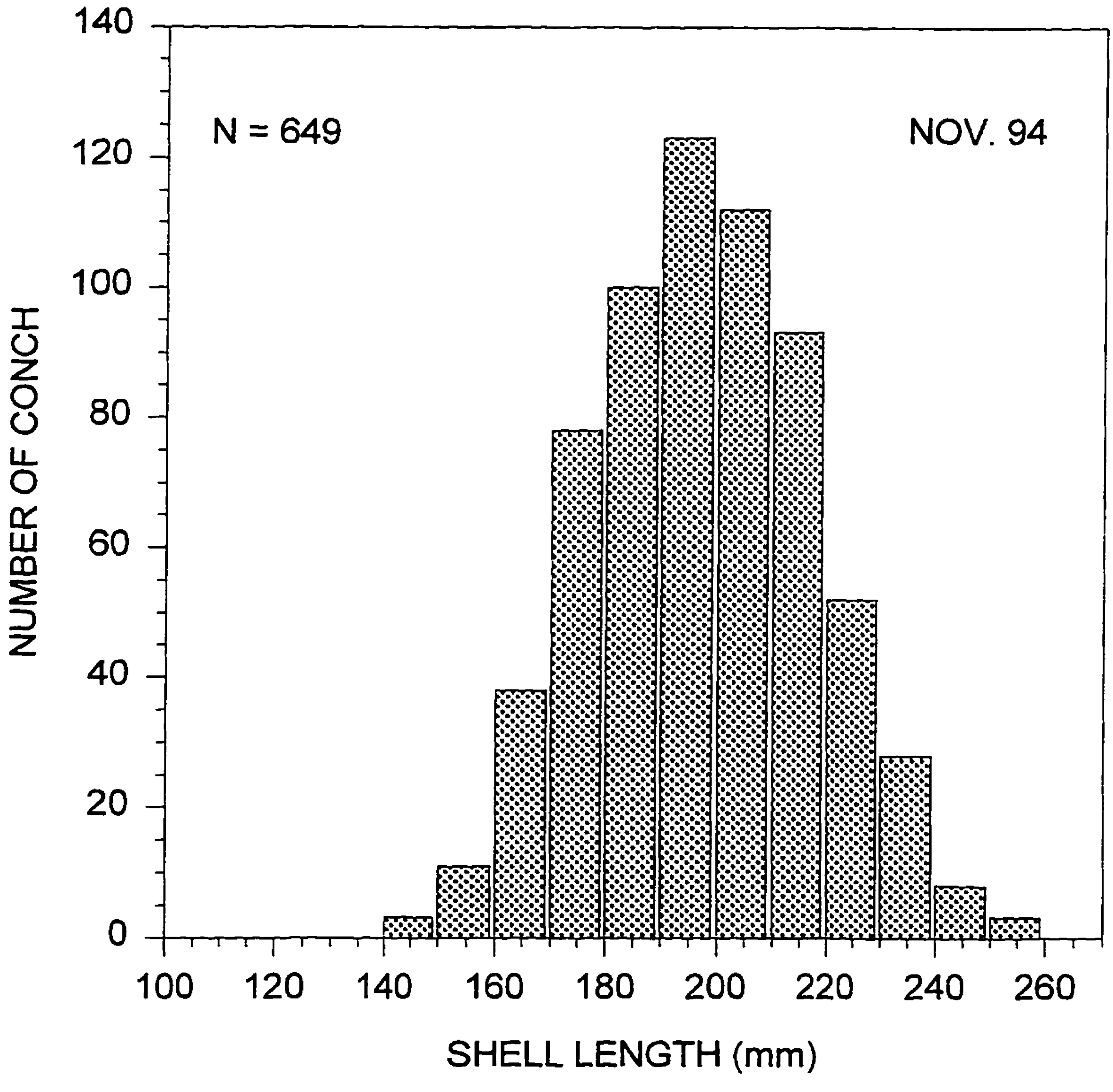

Figure 30. Shell length frequency distribution for lipped conch (sub-adults and adults) collected on Pedro Bank during November 1994 abundance survey.

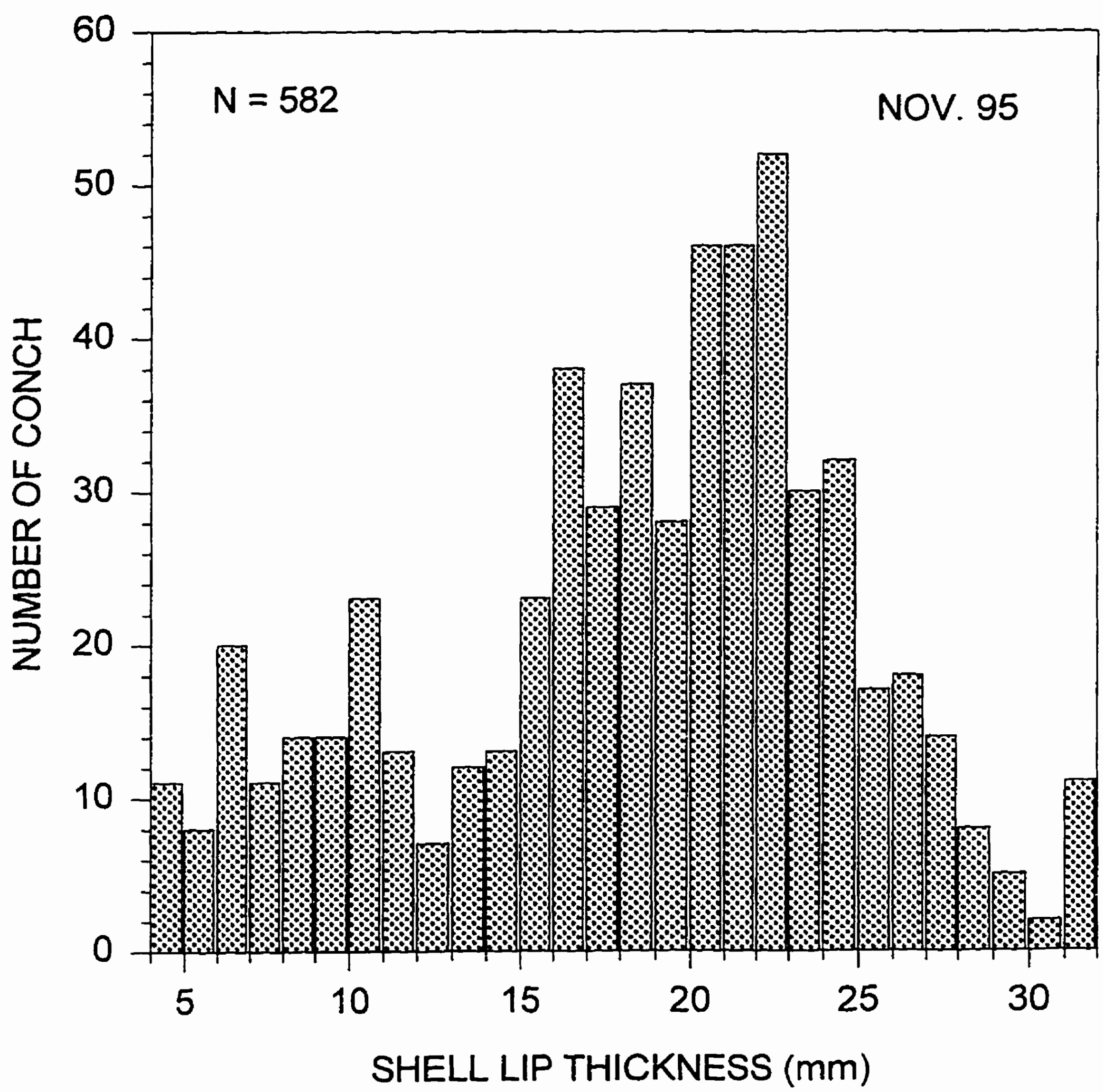

Figure 31. Shell lip thickness frequency distribution for adult conch collected on Pedro Bank during November 1994 abunadnce survey

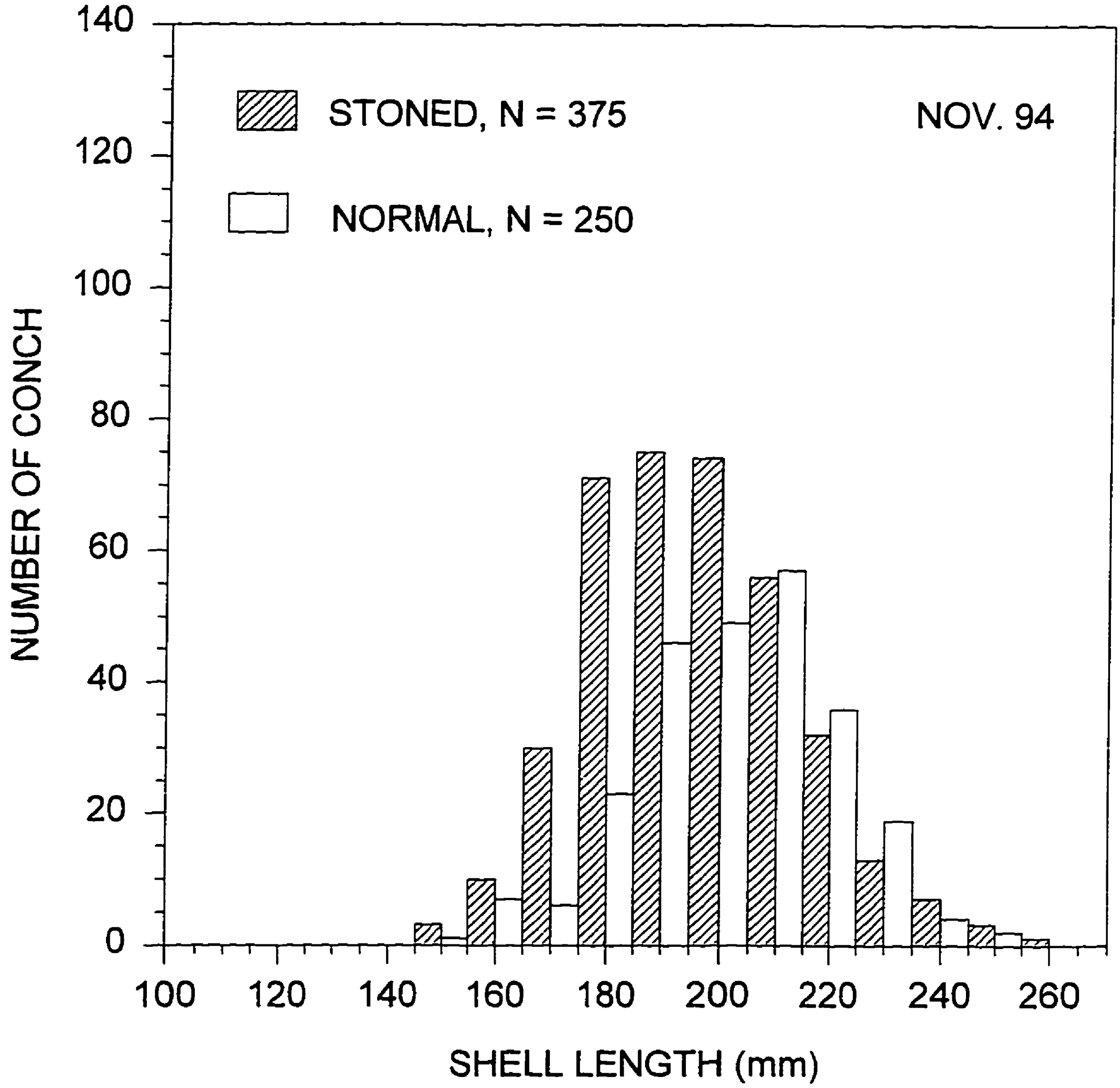

Figure 32. Shell length frequency distribution for adult conch sperated by erosion category (N, S) collected on Pedro Bank during November 1994 abundance survey.

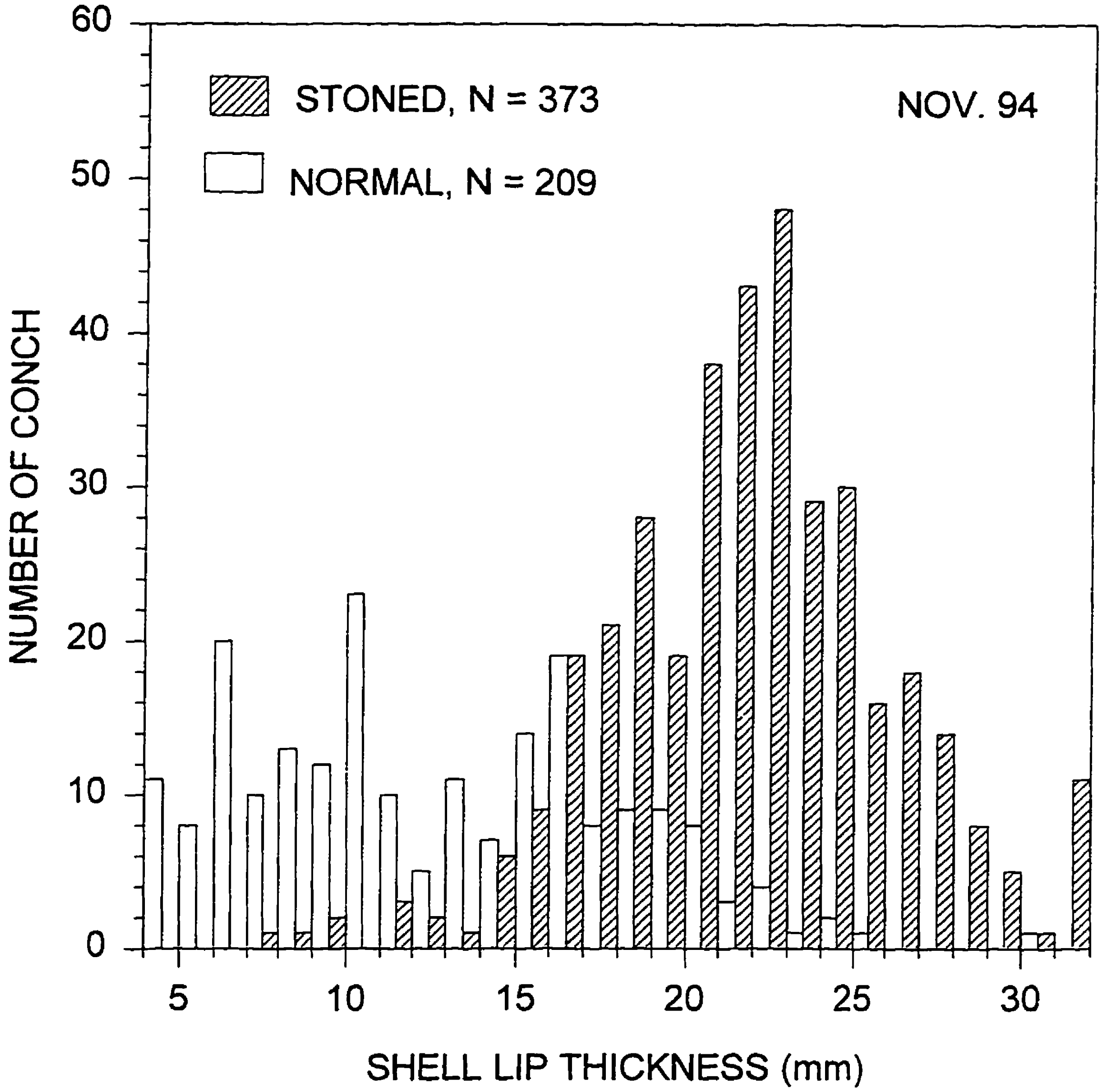

Figure 33. Shell lip thickness frequency distribution for adult conch separated by erosion category (N, S) collected on the Pedro Bank during November 1994 abundance survey

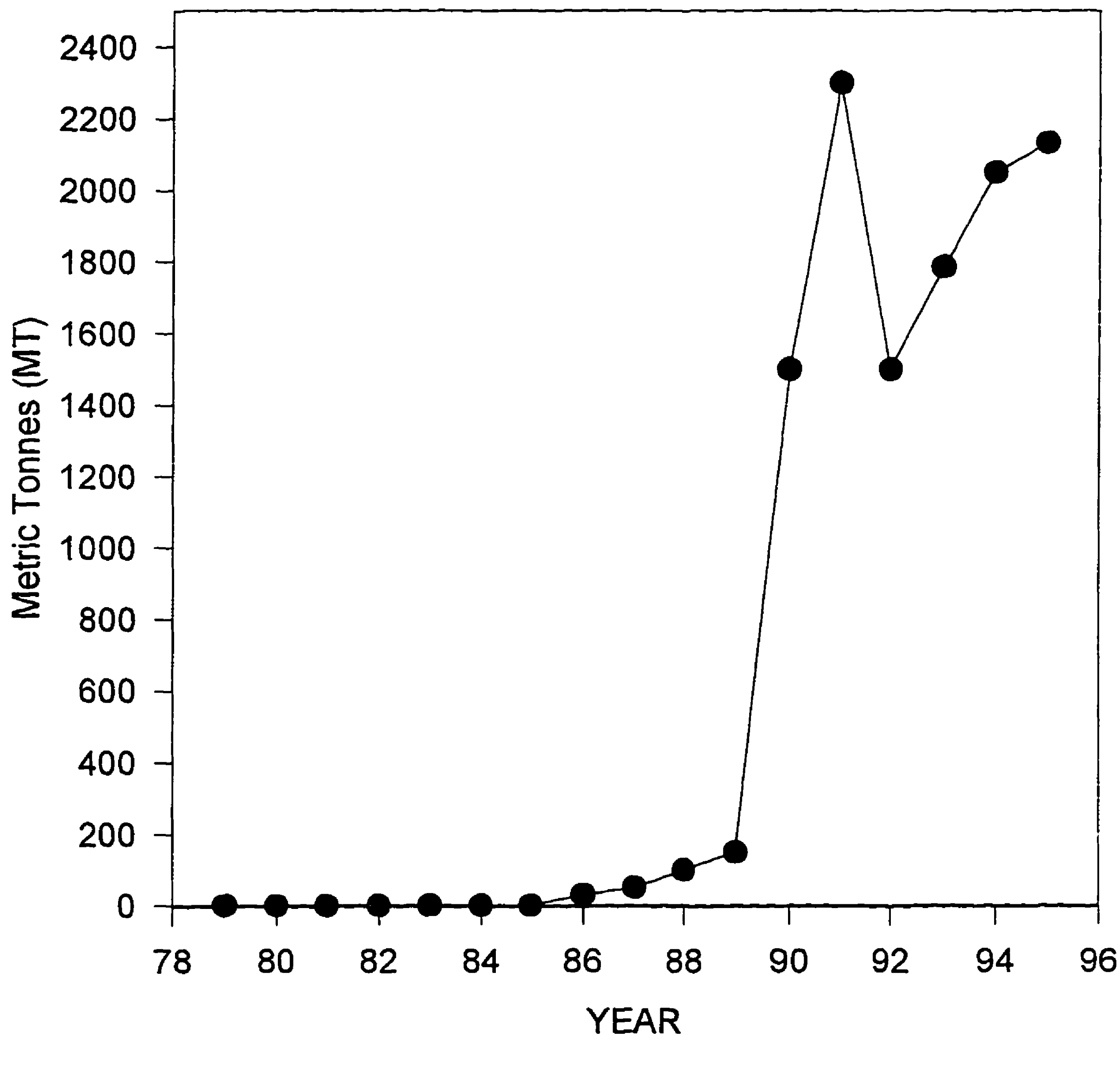

Figure 34. Exports of conch meat (50% grade) in metric tonnes (MT) from Jamaica, 1979-1995