ASSESSMENT OF ARGOPECTEN VENTRICOSUS POPULATION RECOVERY AFTER A COLLAPSE ALMOST TWO DECADES AGO

by

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ABSTRACT

The scallop, *Argopecten ventricosus* supported an important fishery in Las Perlas Archipelago in the 1980´s, after which the fishery totally collapsed due to overexploitation. This study was conducted as intent to determine if the *A. ventricosus* population has shown any sign of recovery after its collapse in Las Perlas Archipelago, in the Gulf of Panama. The study consists of interviews with fishermen and other local residents, collection of data about scallop markets and fishing grounds in the 1980s, and exploratory dredging in these grounds to check if there is any evidence of stock recovery. This study intensively surveyed the major sites of scallop fishery in the 1980's as well as other areas in the Archipelago and no population recovery was found. After the collapse the recruitment rate for scallops has been very low over the last years. The Archipelago is now characterized by a high proportion of very low or zero density sites. Dead juvenile scallop shells were collected as well as a very small number of live individuals. This suggests that minimal recruitment has occurred in the Archipelago and that low densities associated with the lack of suitable available habitats for juveniles, predation and variation in food availability may be the possible factors affecting population recovery. Further studies are suggested in order to determine with certainty the possible causes of these low recruitment rate and the failure of scallop population to recover. Enhancement efforts are necessary to restore the stock, and mariculture techniques are a good alternative to the repopulation of *A. ventricosus* natural banks in Las Perlas Archipelago in the Gulf of Panama.

1. INTRODUCTION

The collapse of fisheries is occurring worldwide. The closure of important fishery areas for cod, haddock and yellow tail flounder such as the George Bank and the Grand Bank off Newfoundland, reflects management reactions to overfishing conditions (Roughgarden and Smith, 1996). One of the worst examples of overfishing is provided by the whaling industry. This has reduced many species of whales to almost extinction and has caused the disappearance of local stocks in different parts of the world. It is known that only 300 right whales survive in the North Atlantic and 250 in the North Pacific Ocean as a result of overfishing. At present, the specie is showing no sign of recovery after its collapse. Other whales such as humpback, blue, fin, Sei whale have also being hunted down to a minimal percentage of their original population (Bryant, 2000).

Other examples of species that have been harvest to commercial extinctions are the California sardine and the red snapper, both were overfished to the point that the fishery never recovered. The Peruvian anchovy fishery was another recent example, which boomed in the 1960s and collapsed in 1970s. Catches of anchovy were above 10 millions tons in the late 1960s to 1971 in Peru. Overfishing caused the collapsed of the fishery during the warming (El Nino) of the 1972 (Bryant, 2000).

Marine species are in a state of decline worldwide. When one population becomes commercially extinct, another species is exploited. Many molluscan fisheries all over the world expanded dramatically in response to availability of increased markets, resulting in intensive exploitation of molluscan species. Scallops are one of the molluscan groups that have had high demands in the recent years. This helps explain why many scallop fisheries are experiencing a reduction in catches and many are collapsing. The scallop genera of most commercial interest are *Pecten, Placopecten, Patinopecten, Aequipecten, Argopecten* and *Chlamys* (Quayle and Newkirk, 1989).

In Alaska, a valuable mollusc fishery is supported by the weathervane scallop, *Patinopecten caurinus*. Recent harvests have occurred in the Westward Region, especially in the waters off Kodiac Island, since the scallop harvests from Southeastern Alaska and Prince William Sound have been insubstantial in past years. A scallop fishery began in 1983 in beds close to Augustine Island, but a rapid depletion of scallop beds occurred, such that by 1985 the last landing report for the area was obtained (Foster, 1997). In Oregon, harvesting of the same weathervane scallop has been

common along the Pacific Coast for years. However, as has occurred with other resources, the depressed prices and lower scallop densities made the fishery no longer profitable after 1990. The best year for landing was 1981, when 16,853,845 pounds of meat were landed. Production in the 1990´s fell steadily, with only 1,805 pounds of meat landed (Robinson, 1997).

Another example of collapsed stocks was the complete closure of the scallop fishery in Tasmania for a period of eight years, due to overexploitation. The Tasmanian scallop fishery is based mainly on the harvest of the commercial scallop *Pecten fumatus*. In 1987 the scallop fishery in the area collapsed. The stock recovered partially and the fishery was opened for short seasons in 1995, 1996, 1998 and 1999 (The Department of Primary Industries, Water & Environment, 2004). In Florida, the commercial scallop *Argopecten irradians* was very abundant before 1990. In the years that followed, over-harvesting caused a decline in the population and it has not been able to recover since its collapse (Marelli et.al, 1999).

In the Pacific area, only two species of the *Argopecten* group still persist, *Argopecten ventricosus* (=*circularis*) in Mexico to Ecuador, and *Argopecten purpuratus* in Peru and Chile. For many decades, *A. purpuratus* has sustained a diving fishery in Independence Bay (Peru) and Tongoy Bay (Chile). Recently, overfishing has caused the closure of the fishery in both bays, and fishermen have reported densities as low as $>0.1/m^2$ (Wolff & Alarcon, 1993). After the depletion of stocks in Chile, Japanese techniques have been used to increase the stock of the species. This has helped in the recuperation of the natural banks (Aguilar & Stotz, 2000). Also, the management of natural banks in Tongoy Bay by fishermen has helped the population recover and has demonstrated potential for sustained exploitation (Aguilar & Stotz, 2000). In Mexico, especially in the State of Baja California Sur, *Argopecten ventricosus* (=*circularis*) supports an important fishery. In 1989, it yielded 5531 tons of fresh meat, but after 1991, a large fluctuation in landing occurred. In 1993, it approached critical levels and was closed in 1994 (Santamaria et.al., 1999). As a result, efforts to preserve the species have been carried out and cultivation has become very important.

In Panama, statistics from the Government (Direccion de Recursos Marinos, 1992) have demonstrated that *A. ventricosus* fishery had a high development in the 1980s. Harvest totals peaked in 1996 and 1997, after which the population declined dramatically, causing a collapse in the scallop fishery. This study is part of a complex study on Las Perlas Archipelago conducted by a UK funded Darwin Initiative Project

and coordinated by Smithsonian Tropical Research Institute (STRI) in Panama and Heriot Watt University. The present study aims to determine if *A.ventricosus* population has recovered after its collapse almost two decades ago, in the Las Perlas Archipelago in the Bay of Panama. The study consists of interviews with fishermen and other local residents, collection of data about scallop markets and fishing grounds in the 1980s, and exploratory dredging in these grounds to check if there is any evidence of recovery of the scallop population.

1.1 GENERAL OBJECTIVE:

The main objective is to determine if the *A. ventricosus* population has shown any sign of recovery after its collapse in Las Perlas Archipelago in the Bay of Panama.

1.1.1 Specific Objectives:

a) To identify the major fishery ground of *A. ventricosus* and collect information about scallop fishery in Las Perlas Archipielago;
b) To identify the relationship between intensive scallop harvest and the disappearance of the species;
c) To Assess A. *ventricosus* stock densities in the Archipelago and identify the possible factors influencing population recovery;
d) To determine possible fishery problems in the Archipelago and the necessity for the creation of new laws that can help in the protection of the marine species.

1.2 LITERATURE REVIEW

1.2.1 Studies about *A. ventricosus*

The scallop *Argopecten ventricosus* (Fig. 1) is distributed along the Pacific Ocean from Cedros Island and the Gulf of California to Paita, Peru (Keen, 1971). It is found in coastal waters at depth ranging from 1-135 m (Villalaz, 1992). In Panama it is

found along the Gulf of Panama in mud-sand sediment that contains a lot of scallop shells (Villalaz & Gomez, 1997). *A. ventricosus* is the most common scallop specie in the Province of Panama in the Pacific Ocean (Keen, 1971).

Figure 1. Valves of scallop Argopecten ventricosus

A. ventricosus shells are characterized by a symmetrical fan shape which contains 21 radial ribs. Both valves in Argopecten are convex but the lower one is more convex. The ears are equal in length and radial ribs are strong and squarish (Quayle and Newkirk, 1989). The scallop *A. ventricosus* has a life span of 2 years and can reach a length size of 6.0 cm (Villalaz and Gomez, 1997).

A. ventricosus is hermaphroditic and a single individual can release both spermatozoa and ova in a single spawning period (Villalaz, 1992). Organisms become sexually mature when their reproductive organs are completely developed (Ministerio de Desarrollo Agropecuario, 2004). Studies conducted on *A. ventricosus* reproduction indicated that initial spawning occurred when the scallop is between the ages of six month and one year old (Tripp-Quezada, 1985; Villalaz and Gomez, 1997).

According to Villalaz (1994) the reproductive cycle of bivalve comprises several stages: vegetative (juvenile); activation; growth and gametogenesis; maturation and resting stages. Various publications have indicated that *A. ventricosus* reproductive cycle requires a lot of energy and it can be obtained directly from food from the environment, or from storage organs or tissues, such as digestive gland, mantle, and adductor muscle (Ansell, 1974; Barber and Blake, 1983). Metabolism in scallop varies depending on age. Small individuals invest more energy in growth than in reproduction (Villalaz, 1994). Once the scallop has increased in size a reduction in the rate of somatic

growth occurs, which allow it to increase the energy allocated for gamete production (Villalaz, 1994).

Temperature plays an important role in *A. ventricosus* development. Difference in growth between grow out zones have been related to temperature, where larger scallop have been harvest in zones with lower temperatures (Sicard et al. 1999). According to Sicard et al. (1999) temperatures between 19 and 22ºC are the optimum temperatures for the *A. ventricosus*. Studies indicate that growth was maximum at temperatures of 19 and 22ºC and lower at lower (16ºC) and higher temperatures (25-28ºC) (Sicard et al. 1999). According to Villalaz, 1992, temperature is important in the initiation of gametogenesis and as a spawning stimulus.

Studies conducted on scallop settlement have indicated that during their early life stages, scallops settle and attach to submerged vegetation that allow them to elevate themselves from the bottom, and get better protection from predators, this allows for higher scallop recruitment and survival (Felix-Pico et al.1989; Ekman 1987; Pohle et al. 1991). Studies conducted by Santamaria et al (1999) suggested *Zostera marina* beds as potential nursery ground for *A. ventricosus* Pacific scallop. According to Santamaria et al. (1999) other types of submerged vegetation must not be ignored since they may also play an important role as substratum to scallop spat.

Minimal studies have examined predation involving *A. ventricosus*. In Panama few records of scallop predation exist. Most of these records were obtained from field study and diving observations. Some of the identified predators of *A. ventricosus* are: some fishes (red snapper), Gastropods (snails), Cephalopods (octopus) and some crabs (Villalaz and Gomez, 1997; Ministerio de Desarrollo Agropecuario, 2004).

1.2.2 Scallop Economic Background

Scallops are bivalves of great economic importance. They have supported important fisheries in Alaska, Oregon, Florida, Peru, Chile and Mexico, but in all these areas fisheries have collapsed due to overexploitation and bad management of the fishery (Foster, 1997; Robinson, 1997; Marelli et.al, 1999; Wolff and Alarcon, 1993; Santamaria et al., 1999). Panama is not an exception to this problem, scallop fishery in the country had a high development for many years, after which the fishery collapsed due to overexploitation. “The Panamanian government first official scalloping statistic in the 1960´s showed that several boats harvested about 300 metric tons of scallop

annually", this data was obtained from Arosemena and Martinez (1986) and presented by Villalaz and Gomez (1997). According to Villalaz and Gomez (1997) no statistics were reported again until 1975, where 6.9 tonnes of scallop meats were reported by the Direccion de Recursos Marinos. In 1976, approximately 143 tonnes of scallop meat worth 351,026 dollars were exported, although no scallop harvest occurred in 1977. No scallop fishery was done until 1982, when 26 tonnes of scallop meat were harvested. Meats export fell to 3.9 and 1.5t during 1983 and 1984 respectively (Villalaz and Gomez, 1997). Scallop fisheries reached their maximum point during the years 1985-1986, when scallops were found and harvested from Veracruz beach to Farallon beach in the Gulf of Panama. Scallops were harvested at depth of 3-20 meters, using shrimp boats and smaller boats. The small boats could harvest half a bushel in 20 minutes or 20 bushel in one day (equivalent to 136 kg of meats) (Villalaz and Gomez, 1997).

According to statistical data collected by Villalaz and Gomez (1997), 4.1 tonnes of scallop meat were exported in 1985. The amount increased to 2,050 tonnes during 1986. The major landing port used by shrimp boats was Puerto Vacamonte; in there scallops were sold to large companies that process them. Small boats brought scallops to beaches and ports where shuckers cleaned them and packed the adductor muscle in bags of 3.5 Kg. The scallop meat was sold by middle men to exporting companies at a price of $6.30/kg. The United Stated of America was the major scallop market; as a result most of scallop meats were exported to this country (Villalaz and Gomez, 1997).

It can be seen that the scallop fishery in the Pacific Ocean of Panama experienced a boom during 1986, which brought new factories and more investment to the country. Scallop fisheries became an important industries that created new jobs, especially in the areas most affected by unemployment. As a result of these developments many shrimp vessels changed their fishing activities to the extraction of scallops during the months of February and March (Gaceta Oficial, 1987). During this period of intensive harvest, conflicts between small boats and shrimp boats were developing, because the artesanal fishermen claimed that scallop beds were being depleted by the larger commercial shrimp boats. As a result, the Government of Panama decided to create regulations to maintain the continuity of the scallop fishery and to have a better control over it (Gaceta Oficial, 1987).

By the Decree No 6. (February 3, 1987) the Government of Panama created transitory measures concerning the scallop fishery of the Gulf of Panama, during the months of February and March 1987. According to these regulations, the shrimp vessels

dedicated to the scallop fishery during the year 1986 had to obtain new permits and must have the appropriated equipment to work in the scallop fishery during 1987. These regulations also required that shrimp vessels were excluded from scallop fishing areas within 4.5 km (3 miles) of the coast, from Farallon to Veracruz, since these areas were designated to the scallop fishery for small boats (Gaceta Oficial, 1987).

Today, the scallop fishery in the Gulf of Panama has totally collapsed and fishermen are again dedicated to the fish and shrimp fishing activities. With the complete disappearance of the scallop, the economic life of the communities was greatly upset.

2. MATERIALS AND METHODS

2.1 DESCRIPTION OF THE STUDY AREA

The study was conducted in Las Perlas Archipelago, situated in the Gulf of Panama, on the Pacific Ocean (Figure 2). It is localized within the coordinates 8°11´31´´, 8°40´16´´of latitude north and 78°46´22´´, 78°08´40´´of West longitude and has an approximate area of 33,176-ha. Las Perlas Archipelago can be divided in two parts: the south area, which contains the three bigger islands (Del Rey, San Jose and Pedro Gonzalez islands) and other smaller islands; and the north part which has the majority of the islands such as Contadora, Saboga, Taboga and others, located to the northeast of the Gulf of Panama.

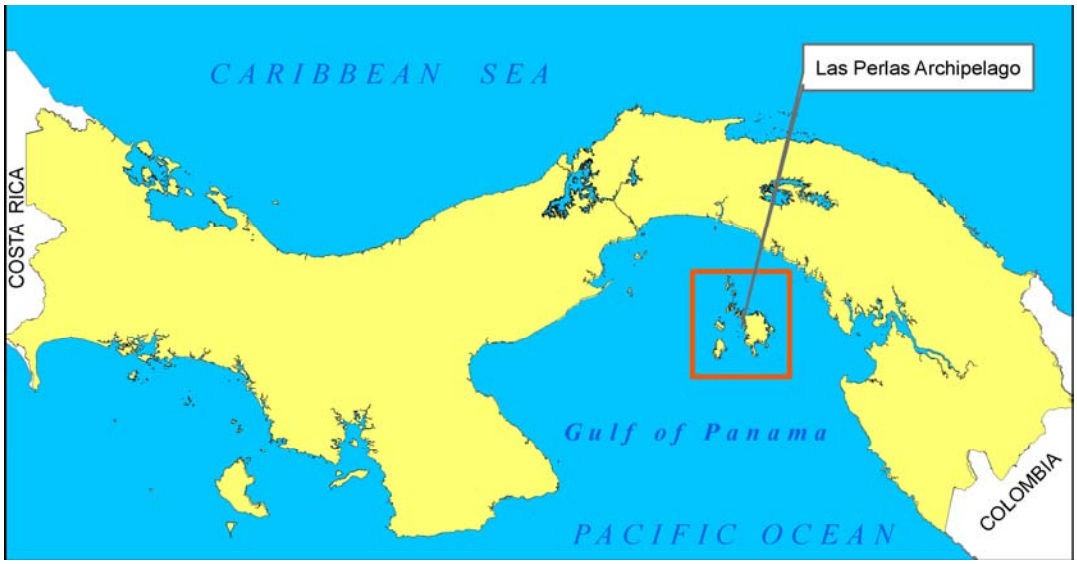

Figure 2. Map of Las Perlas Archipelago in the Republic of Panama

The Gulf of Panama is subject to variable environmental conditions as a result of two events, a wind driven seasonal upwelling and a sea-warming caused by El Niño southern Oscillation (D´Croz and Robertson, 1997). Upwelling occurs during the dry season from January to April when northerly winds displace nutrient poor coastal water to the surface, which produces blooms of phytoplankton (D´Croz et al., 1991). Seasonal upwealling is responsible for changes in water temperature, nutrient level, sea level and rainfall (D´Croz et al, 1991). During the rainy season, between May and December the Bay of Panama has warm, low salinity and nutrient poor waters (D´Croz et al., 1991).

Water temperatures in the Gulf of Panama can range from cold (15-20°) during seasonal upwealling to warm (30-31°C), which occurs during El Niño-Southern Oscillation (ENSO) events (D´Croz, et al. 2001). Salinity during the dry season usually ranges from 32 to 35‰ and is generally below 30‰ during the rainy season (D´Croz et al., 1991). Annual gross production rate ranges from 255 to 280 g C m^2 (Forsberg, 1969). Tides in the Gulf of Panama are semi-diurnal and amplitudes may reach up to 6m (Glynn, 1972).

2.2 COLLECTION OF DATA

The study consists of various sections: fishermen interviews, artisanal survey, and cruise expedition surveys. Additional information on statistical data about *A. ventricosu*s economical fishery production during the past 20 years was obtained through interviews with governmental authorities. Water temperature data recorded in the Archipelago for the past 20 years was also obtained and analysed.

2.2.1 Fishermen Interviews

The interviews were carried out from May 15 to May 30, 2004 in the Archipelago. The purpose of the interviews was to identify the sites where *Argopecten ventricosus* was exploited approximately 2 decades ago and to collect information about the scallop fishery in the area. The data was obtained by interviewing fishermen and other local residents of the Archipelago, specifically from the communities of San Miguel and Martin Perez in Del Rey Island, and also from Contadora, Saboga, Casaya and Pedro Gonzalez Islands. As large a number of fishermen as possible were interviewed. Priority was given to fishermen older than 35 years of age, since scallop exploitation occurred approximately 15-20 years ago. Approximately 157 individuals were interviewed, half of whom affirmed that they had been part of the scallop fisheries in the 1980s. The interview's questions were designed in such a way that the major information about scallop fishery in the Archipelago could be obtained. The interviews included questions such as where scallop was harvest, what methods were used, how much was harvested, the prices of scallop in the market and what fishermen considered to be the cause of the scallop fishery collapse.

2.2.2 Artesanal Survey

Once the fishery sites have been identified, a second field survey using artesanal fishing methods was carried out from June 17 to June 19, 2004 to determine if *Argopecten ventricosus* populations had recovered. For the survey, a dredge of 0.823 m long x 0.304 m width was used. A 1 m long net was attached to it (Figure 3). The design was an exact copy of a dredge obtained from the fishermen of Casaya Island during the interviews survey. The boat used for the survey was a motor boat 6 meter length, the same type used regularly by fishermen of the area. Two fishermen, who had been active members of the scallop fishery at that time, were contracted as guides to point out the areas where scallop fisheries used to be carried out. The information provided by them was correlated with the information obtained from the rest of the fishermen during the first survey.

Figure 3. Dredge used during the artesanal survey

The surveyed area was divided into 39 sample stations, ranging from 6 to 23 meters in depth (Figure 4). Dredging was undertaken at each station at a velocity of approximately 3.5km/h, for a period of several minutes until the weight of the net caused a decrease in the boat velocity indicating that the net was full. This was the same method used by the fishermen at that time. The samples were sorted out, and the numbers and size of scallop shells collected were measured. The quantities and size of dead adult scallop shells were approximately determined. The height and length of

juvenile scallop's shell were measured using calipers. The site location, depth, and substrate type where the survey was carried out were also noted.

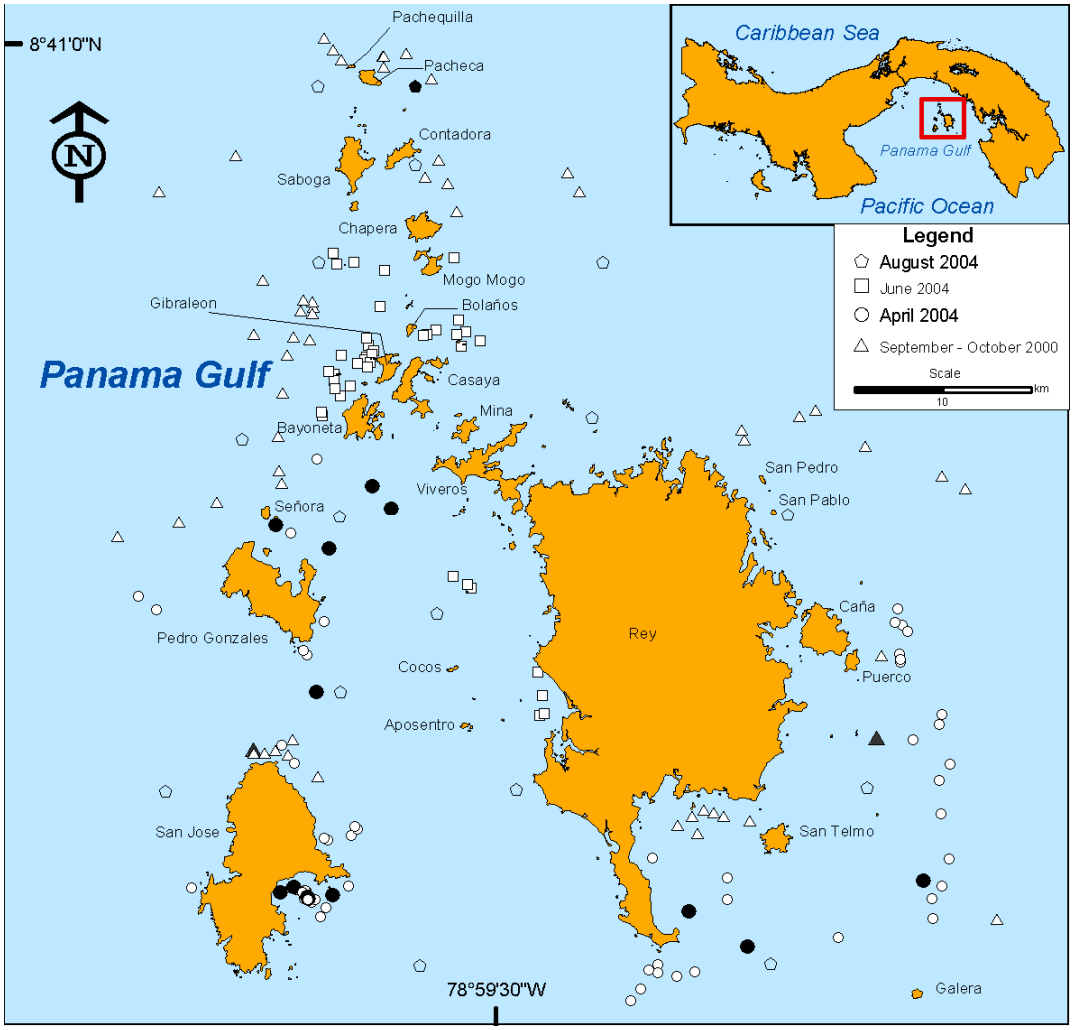

Figure 4. Map of Las Perlas Archipelago and Survey stations. The triangles indicate stations surveyed during the 2000 cruise expedition, the circles indicate stations surveyed during the April 2004 cruise expedition, and the squares indicate stations surveyed in the June 2004 artisanal survey. The pentagon indicate the station surveyed during August 2004 Darwin project survey.The dark triangles, circles and pentagons are the stations where live *A. ventricosus* were found.

2.2.3 Other Surveys

The artisanal survey only covered the areas that fishermen identified as scallop fishery sites in the 1980s. These areas were in shallow waters at depth no greater than 23 m and very close to the coast. In order to have a higher coverage of the Archipelago (including areas at higher depths) and obtain a better picture of *A. ventricosus* distribution along the Archipelago, additional data was collected from two previous cruises conducted in the Archipelago by Smithsonian Institution researchers (Harilaos Lessios and Rachel Collins).

The first cruise expedition was carried out from September 26 to October 1, 2000 (Figure 4). Fifty-seven stations were done in total using commercial dredges of 0.76 m long x 0.46 m width with a 1.20 m long net attached to it (Figure 5). Dredging was done around the whole Archipelago at depth ranging from 15 to 90 m, for a period of approximately 5-10 minutes at each station. The second cruise expedition, which occurred April 6-11, 2004, consisted of seventy-four stations done in total using the same method (Figure 4). Dredging was done at depth ranging from 6 to 67.5 m. Benthic organisms were collected and recorded, although for the current study only the information on *A. ventricosus* was used.

In order to fill gaps from previous surveys, we carried out a last cruise expedition in the Archipelago from August 10-20, 2004, as part of the Darwin Initiative Project (Figure 4). During the survey, information was collected from 13 stations between 15-66 m depth. In these cruise expeditions we applied the same methodology previously used in Smithsonian cruise expeditions by Lessios and Collins.

Figure 5. Commercial dredge used during Smithsonian cruises surveys and during the Darwin Project Cruise survey.

2.2.4 Scallop Statistic Data

Statistics on scallop fishery production during the past years were obtained through interviews with Governmental authorities, specifically from the Direccion de Recursos Marinos (a branch of the Autoridad Maritima de Panama in charge of administration of marine resources) and the Contraloria General de la Republica de Panama. The purpose of the interviews was to collect statistical data on reported amount of scallop catches from the year 1981 to 2004 such that variations in scallop fishery production in the past years could be analysed.

2.2.5 Temperature Data

Temperature analysis was undertaken to determine if major temperature changes in sea surface has occurred during the past years. Temperature data were used to relate field observations with estimated geographic temperature anomalies. Weekly mean sea surface temperature (SST) anomalies from November 1981 to June 2004 were obtained from the Integrated Global Ocean Services System (IGOSS; http://ingrid.ldgo.columbia..edu/SOURCES/.IGOSS/.nmc/.weekly/.dataset_documentation.html). Temperature records were divided in four quadrants for Las Perlas Archipelago, Northeast, Northwest, Southeast and Southwest. Temperature

measurements were blended from ship, buoy, and bias-corrected satellite data (Reynolds & Smith 1994).

3. RESULTS

3.1 INTERVIEWS RESULTS

Through the interviews, *A. ventricosus* fishery sites were identified and information about scallop fishery in the Archipelago was obtained. We also obtained a perception of some of the fishery problems in the area and identified the necessity for better control on fishery regulations in Las Perlas Archipelago. Approximately 157 individuals were interviewed in 6 communities of the Archipelago. The minimum number of interviews was done in Pedro Gonzalez island (11) and the maximum number in the community of San Miguel in Del Rey Island (62) (Table 1).

Area	***Community***	***Number of interviews***
Las Perlas Archipelago	San Miguel	62
	Casaya	13
	Martín Pérez	15
	Contadora	36
	Saboga	20
	Pedro González	11
Total	6 communities	157

Table 1. Communities interviewed during the survey

3.1.1 Scallop fishery sites Identification

The fishermen interviewed on the Panamanian islands of Casaya, Contadora, Pedro González, Del Rey Island, and Saboga, identified *A. ventricosus´s* fishery sites as follows: In areas near Del Rey Island (around the communities of San Miguel, Martin Perez, La Guinea, La Legua) Bayoneta, Casaya, Pedro Gonzalez, Gibraleon, Churra-Churra, Saboga, Bolaño, Contadora, Boya Arena, Mogo-Mogo, Buen Nombre, Apocento, Membrillo, Vivero, Santa Catalina, La Esmeralda, and Bartolome islands. Most of these areas are situated on the west side of Las Perlas Archipelago.

3.1.2 Scallop fishery in the Archipelago

Information about the scallop fishery activity in the archipelago in the 1980s was also obtained from fishermen's interviews. According to fishermen, extensive exploitation of scallop in Las Perlas Archipelago occurred between 1985, 1986 and 1987. After 1987 the number of scallops in the Archipelago began to decline, and by 1989 the resource had completely disappeared. Some fishermen stated that extensive exploitation occurred for a period of 7 years, while others said that it only occurred for a period of 2 to 3 years. They also point out that scallop fishery in the Archipelago began in La Guinea at the mouth of Rio Sucio, and from there it expanded to Pedro Gonzalez Island and the rest of the Archipelago.

According to fishermen, scallop fisheries brought a period of wealth and great development to the archipelago. The scallop market also brought people from different areas of the country to the archipelago to work in the scallop fishery. Fishing was done using small motor boats of 6 and 10 meters in length, with one or two dredges pulled by hand. According to fishermen, each boat could harvest approximately 8 to 20 bushels of scallops per day that could yield approximately 100 to 700 pounds (54-136 kg) of scallop meat depending on the size of the boat, the number of dredges used, and the number of hauls per day. Scallop meat from the archipelago was sold at about $1.00/lb to intermediaries, who in turn, sold it to exporting companies at a price of $2.00/lb. Fishermen indicated that most of the scallop meat was sent to the United States. Scallop shuckers in the archipelago got paid approximately 0.50 cents per pound.

Fishermen indicated that sometimes the amount of scallops harvested was so high that not enough shuckers were available on the islands to clean them all. This resulted in the unshucked scallops putrefying and being thrown back into the sea. According to fishermen from the archipelago, the problem began when shrimp boats became part of the business. They used bigger boats with larger nets and had no consideration to the amount of catch and scallop size. Fishermen stated that the scallop ground started to decrease when fishing boats started operating in the same areas as them, causing an increase in the number of catches. They said that in the Archipelago no regulations on exclusion zones for shrimp boats existed, such that they could harvest in any area of the Archipelago without restriction.

The majority of the fishermen recognized overfishing as the cause of scallop collapse in the Archipelago. Most of them admitted that sometimes the amount of catches was so high that they could not handle it, resulting in high amount of scallops lost. A minority of fishermen attribute the scallop disappearance to other reasons such as scallop migration and seasonality. According to these fishermen "scallop got scared, when they saw the dead shell of other scallop in the sea, and they run away". Fishermen from the Archipelago also admitted that in recent years the amount of marine species, such as the lobster, octopus, red snapper and other important species are decreasing considerably in the Archipelago.

3.2 ARTESANAL SURVEY RESULTS

During the current artesanal survey, a total of thirty-nine stations were sampled in Las Perlas Archipelago using dredging but no live *A. ventricosus* organisms were found (June 17-19, 2004) (Refer to Figure 4 and Table 2). A significant number of empty juvenile scallop shells (approximately 800 hundred) ranging from 0.7 to 3.5 cm were recorded in areas close to Buen Nombre, Mogo-Mogo Island, Santa Catalina Island, La Legua beach, Churra-Churra, Gibraleon Island, and Bolano, at depths between 9 to 23 m in sandy sediment. A comparison between the sizes of the shells collected during the survey with preliminary scallop size data recorded by the University of Panama, indicated that the collected shells could be between 3 to 5 months old, probably younger. The collected shells seemed very fragile and appeared to be very recent.

3.3 OTHER SURVEYS RESULTS

In the first cruise expedition conducted from September 26 to October 1, 2000, 57 stations were surveyed. *A. ventricosus* was collected at seven of these stations at depths ranging from 16 to 90 meters. About 10 to 15 live individuals of approximately 2 to 3 cm diameter were found in only two of the before mentioned stations, namely to the north of San Jose Island and near Puerco Island (Refer to Figure 4 and Table 3).

During the second cruise expedition, carried out April 6-11, 2004, seventy-four stations were surveyed. Approximately 15 to 20 live individuals between 1.5 cm and 2.5

cm diameter were found in fifteen of these stations in areas near Vivero Island, Pedro Gonzalez Island, San Jose Island, Galera Island and Punta Coco, at depths ranging from 10.6 to 30.2 m (Refer to Figure 4 and Table 3).

In the last cruise expedition carried out in the Archipelago (August 10-20, 2004), as part of the Darwin Project Initiative, 13 stations were sampled. Only one live *A. ventricosus* with a size of approximately 3.01cm height, 3.26 cm length and 1.27 cm width, was recorded to the East of Pacheca Island a depth of 25m. (Refer to Figure 4 and Table 4).

3.4 STATISTIC DATA RESULTS

Interviews with Governmental authorities from the Direccion de Recursos Marinos and La Contraloria General de la Republic, allowed us to identify a serious problem in the management of fishing records. The Government of Panama does not have records on specific amounts of scallop exportation to other countries. Scallops are recorded under the crustacean and mollusc category, which is a very wide and general category. As a result, we could not determine the specific scallop exportation amounts; we could only obtained statistic data on scallop production from 1980 to 2004 in Panama.

Landing statistics obtained from the Panamanian Government show a considerable increase in scallop's fishery production during 1986 and 1987 (Fig. 6) (Direccion General de Recursos Marinos, 1992). This information correlates with the years of intensive scallop exploitation indicated by the fishermen of Las Perlas Archipielago. A marked decrease in scallop production was observed after 1990, when only 1 metric tonne of scallop production was reported in 1991. After 1992 no report on scallop production was obtained until 1998 and 1999 when 3 and 7 tonnes, respectively, were recorded (Direccion General de Recursos Marinos 2004: Panama en Cifras, 2003). According to statistics obtained from Direccion de Recursos Marinos (2004), no scallop production has been reported in the country after 1999.

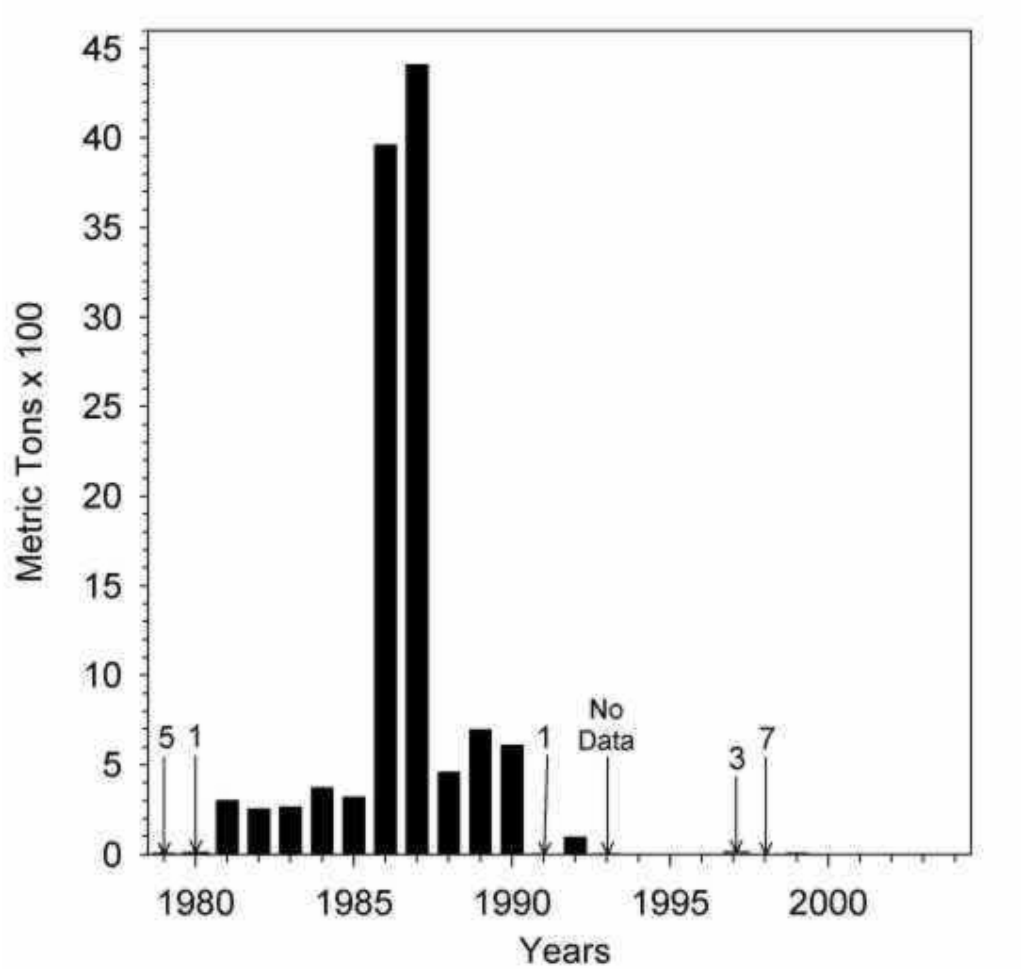

Figure 6. *Argopecten ventricosus* fishery production statistics (1981-1991) (Direccion General de Recursos Marinos, 2004).

3.5 TEMPERATURE RESULTS

Weekly average temperature records from November 1981 to June 2004 in the Archipelago were used to relate field observations with estimated geographic temperature anomalies. Temperature in the Gulf of Panama can range from cold (15-20° C) during seasonal upwelling to warm (30-31°C), which occurs during El Niño-Southern Oscillation (ENSO) events (D´Croz, et al. 2001).

Temperature records obtained from the Integrated Global Ocean Services System indicated that temperature in the Archipelago was normally maintained between (26-28°C), although minimum average temperatures as low as 23°C were recorded during the dry season as a consequence of upwellings. The maximum average temperatures of 30.2^{o}C were recorded during the years 1983, 1997 and 1998, which

coincide with El Nino phenomenon that took place in the area during these years. Temperature anomalies have not indicated dramatic changes of temperature; it has maintained within the ranges of the area. In the temperature anomalies graphs the greatest anomalies are observed during the upwelling and El Nino periods (Figure 7). Low temperature anomalies were reported during the first months of each year, which coincide with the upwelling season. The lowest temperature reported an anomaly of -4 ^{o} C (compared to regularly recorded temperature of 26-28° C) in 1989. Highest temperatures reported an anomaly of 2.5^{o} C (compared to regularly recorded temperature of 26-28° C) and were recorded during the years 1983, 1997 and 1998, as already mentioned. In the graphs we can also observe small temperature differences between regions in the Archipelago. The highest and lowest temperature were observed in the Southwest and Southeast regions (Figure 7).

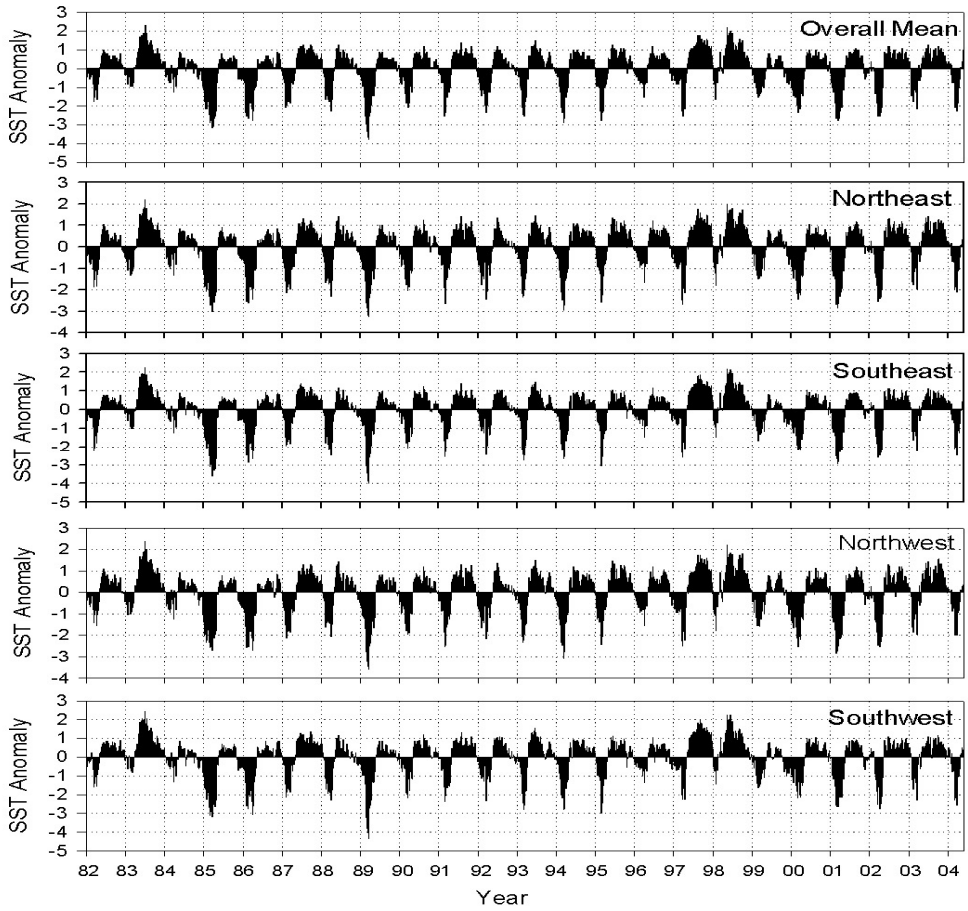

Figure 7. Temperature anomalies recorded in the Archipelago (1982-2004).

4. DISCUSSION

Before this research was conducted no studies and publications existed about the scallop fishery in the Las Perlas Archipelago. Information was obtained on the Archipelago fisheries from artesanal fishermen, statistics from the government of Panama, and intensive benthic surveys. Research so far indicates there has been little sign of recovery of stocks since the collapse of the scallop fishery almost 20 years ago.

4.1 Reasons for Initial collapse

The reason for the initial scallop fishery collapse is probably due to a combination of factors:

- Overfishing
- Lack of regulation
- Market Demand and scallop fishery as the only source of income

Each of these reasons will be explored in turn.

4.1.1 Over-fishing

The scallop fishery brought a period of wealth and great development to the Archipelago, as a result the islands became host to populations that moved from other regions of Panama to the Archipelago to work on the scallop fishery. During the years of intensive scallop harvest, the major activity in the Archipelago was the scallop fishery. Since it was a profitable activity everybody in the Archipelago become part of the business, working on different activities of the fishery (as fishermen, shuckers, and intermediates).

In this study estimation on scallop catches volume per boat was approximately determined, and it is considered that despite the scallop fishery being undertaken using artesanal methods the amount of scallop harvested was extremely high. According to fishermen scallop densities started to decrease when shrimp boats became part of the business and started fishing in the same areas as them. No doubts exist about this, but the depletion of the stock and further collapse of the fishery was the result of

overfishing pressure of both artesanal and commercial fishing. During the intensive fishing periods, the scallops were harvested without discrimination of size or age. It appears that the scallops stocks were fished over their maximum sustainable yield; no time was given for reproduction so that not enough recruitment occurred to maintain the population.

Governmental statistics on scallop production from 1981-2004 demonstrated that 1986 and 1987 were the years with highest scallop production in the Republic of Panama (Dirección General de Recursos Marinos, 1992, 2004; Autoridad Marítima de Panamá, 1998: Panama en Cifras, 2003). These years correlate with the years of intensive scallop harvest in the Archipelago, after which stocks began to decline. After 1990 minimal or no reports on scallop catches has been recorded by the Direccion de Recursos Marinos (2004). These statistics added to information obtained from fishermen of the Archipelago clearly indicated that intensive scallop harvesting is the cause of the disappearance of the species.

4.1.2 Lack of Regulations

Regulations on scallop harvesting did not exist in the Archipelago before 1986, when the highest catches were recorded by the Government (Direccion General de Recursos Marinos, 1992). Assuming that legislation passed on in other areas of the Gulf of Panama specifically Veracruz and Farallon, in February, 1987 were applied to the Archipelago, these do not control fishery harvests until 1987 when scallop grounds were already in a state of decline due to overfishing.

Fishing regulations exist in the Archipelago at present; the problem is that nobody is responsible of making sure that these regulations are complied. The high fishing pressures on other species in the Archipelago are leading to the reductions of species stocks and possibly to further collapses of other fisheries in the area, exactly like what happened with the scallop fishery.

4.1.3 Market Demand and Only Source of income

The availability of markets for *A. ventricosus* was also a possible cause of scallop fishery collapse; exporting companies buy the scallop at good prices, making

the scallop fishery a profitable activity for fishermen. Scallop intensive fishing occurred in the Archipelago because at that time the population depended on fishing for their subsistence and it was basically the only source of income in the Archipelago.

Fishermen in the Archipelago concentrated on the fishing of species with commercial values that could give them more revenues. As a result, species like lobster, octopus, and red snapper between others are identified by fishermen as the more valuable and fished today. Fishermen admitted that in recent years the number of marine species have decreased substantially; but since the majority of the population have low levels of education, poor or no knowledge exist about overfishing and the problems that can originate as a consequence of it.

4.2 Causes of Low Recruitment Rate

This study has intensively surveyed the major sites of scallop fishery in the 1980's as well as other areas in the Archipelago, and no population recovery was found. After the collapse the recruitment rate for scallops has been very low over the last years. The possible reasons for this are:

- Low Stock levels
- Temperature changes
- Lack of suitable available habitats for juveniles
- Predation
- Food Availability – Upwelling

4.2.1 Low Stock Levels

Dead juvenile scallop shells were collected as well as a very small number of live individuals. This suggests that minimal recruitment has occurred in the Archipelago and that low densities are affecting population recovery. Studies conducted by Marelli, et al. (1999) on *Argopecten irradians,* have demonstrated that in populations at low densities, recruitment is likely to fail because low fertilization success may act against recovery. Natural recovery may take a decade or more and enhancement efforts are necessary to restore the stock.

4.2.2 Temperature Changes

Temperature could be one of the main factors that may affect directly or indirectly larval and adult survival. Studies conducted by Sicard et al. *(1999*) indicated that the optimum temperature for *A. ventricosus* juvenile population growth is between 19 and 22°C. Weekly average temperature recorded from Las Perlas Archipelago has shown low temperatures of 23°C during 1985 and 1986. Since these temperatures are average temperatures it is probable that temperature of 21-22° C had been registered in the Archipelago.

These low temperatures coincide with the upwelling season that brings colder, more saline and nutrient rich water to the surface, which allows an increase in the growth of phytoplankton (D'Croz, 1991). According to Villalaz (1992) phytoplankton enrichment and lower temperature could explain in part the high survival of scallop in 1986 and the productive scallop fisheries in 1985 and 1986. Based on temperature analysis, similar conditions were recorded in the area in 1989. This year correlates however with the period of scallop production decrease reported by the Government of Panama due to the overfishing. This suggests that even though conditions were ideal for scallop survival, the scallop population was not able to withstand the rapid and intensive overexploitation of the stock in the Archipelago. Drastic changes of temperature have not been reported in the Archipelago during the past 20 years, therefore it is unlikely that temperature effects may have caused juvenile mortalities.

4.2.3 Lack of suitable available habitats for juveniles

According to Arsenault and Himmelman (1996) the use of refuges decreases the risk of predation for smaller scallop. Studies conducted by Santamaria et al.(1999) have suggested the temporal coincidence of the Annual *Eelgrass Zostera* and juvenile *A. ventricosus* in Bahia Concepcion, Mexico and the possibility that eelgrass beds could be used as nursery grounds by these scallops. In Panama no studies exist about submerged vegetation as possible refuges for *A. ventricosus*. This type of studies could give an explanation to juvenile mortalities in the Archipelago. It could be possible that refuge vegetation were affected by dredging methods during intensive scallop exploitation, resulting in refuges disappearance and higher risk of juvenile predation.

4.2.4 Predation

According to Nadeau and Cliche (1998) predation is an important factor affecting the survival of juvenile scallops between seeding and harvest. Studies conducted on predation of sea scallop (*Placopecten Magellanicus*) indicated that crabs (Cancer *Irroratus* and *Hyas* Sp) and starfish (*Asterias vulgaris, leptasterias polaris and Crossaster papposus*) are scallop predators, and are responsible for juvenile scallop mortalities after seeding (Nadeau & Cliché, 1998). This could be a possible answer to scallop juvenile's mortalities in the Archipelago, since in Panama reports on scallop predators such as fishes, portunid crabs, gastropods, octopuses and starfish have been recorded. No specific studies have been conducted in the Archipelago or other areas of Panama about *A. ventricosus* predation.

4.2.5 Variation in food availability

Another possibility of low scallop recruitment could be the variation in food availability. According to Villalaz (1992) the Gulf of Panama had enough food to support a substantial population of scallops. Weak upwellings were reported during the years 1998, 1999 and 2000 (D´Croz *et al*., 2003). It is possible that variation in food availability, as a result of these low upwellings, may have something to do with juvenile mortalities.

Juvenile scallop mortality and low recruitment could be attributed to different reasons but since minimal or no studies have been conducted in the Archipelago on scallop predation, diseases, competition, food availability, and other factors that may affect *A. ventricosus*, it is not possible to determine with certainty the possible causes of population failure to recover. Further studies are suggested in order to identify the reasons for these high mortalities and low recruitment densities.

Taking into account that adult individuals were not found, it is possible that juvenile larvae could come from other areas of the Panama Gulf, where adult individuals of A. *ventricosus* have been reported. Another possibility is that they came from an experimental mari-culture project that the Ministerio de Desarrollo Agropecuario (MIDA) has in San Jose Island in the Archipelago de Las Perlas.

Our results indicated that once a resource collapses due to over exploitation the possibilities that it could recover are very limited. Many factors work together in the

maintenance of a species, once a total collapse occurs the species would depend on the right environmental and physiological conditions for its recovery, something that is very difficult to occur.

Countries like Chile, Mexico, Canada and United States have used mariculture technologies to increase scallop stocks and to repopulate natural banks (Aguilar & Stotz, 2000; Nadeau & Cliché; Sicard et al, 1999). Recently, Panama has followed these steps, and has seen mari-culture techniques as an alternative to increase species stocks. Studies on scallop repopulation have been conducted by the Ministerio de Desarrollo Agropecuario (MIDA) with the advice of the Centro de Investigaciones Biologicas del Noreste, S.C. (CIBNOR) of Mexico. The project started in the year 2000 when adult scallop (5-6 cm) were obtained from an experimental culture in Mexico and were kept in the Pacific Mariculture Station in Panama. Adult spawning was induced through thermal stimulation (18-24-26-18º C). Larvae culture was realized in fiber glass tanks with 500 litters of sea water filtered and chlorinated. Larvae were feed with *I. Galbana* and *Ch. Calcitrans*, and kept at temperatures of 24-25ºC, at salinities of 36%. Larvae mariculture had a high success such that some larvae were donated to The University of Panama for further studies (Guerra-Lima et al, 2002).

After reaching a size of 0.4 cm, scallops were transported to sea-culture sites in the communities of Farallon, in the Province of Cocle (Mazon-Suastegui et al. 2004). Further seeding has been done in San Jose Island in Las Perlas Archipelago with high success.

Mari-culture techniques developed in Panama are a big step on scallop reproduction. The high success on scallop culture in Panama has opened the possibilities for research on scallop mortality, predation, competition, reproduction and other causes that may be affecting population recovery. These techniques should be investigated further as they could lead to the repopulation of *A. ventricosus* natural banks and to the possible recovery of the stock in the Archipelago.

5. CONCLUSION

The intensive exploitation of *A. ventricosus* populations, almost two decades ago, is the principal cause of the disappearance of the species in this region. It is likely the short life span of the species combined with overfishing in the area brought the scallop fisheries to a complete collapse. These reasons are similar to those described by Villalaz and Gomez (1997) for the same species in another area of the Bay of Panama (Farallon, Veracruz and Parita Bay). The scallops were also non-selectively harvested in relation to size and age. Therefore no recovery time was available for reproduction, the specie was fished beyond its MSY and not enough recruitment occurred to maintain the population.

Today, almost two decades after the scallop fishery collapsed in the Archipelago, no population recovery has occurred. High proportions of the sites surveyed within the Archipelago now have very low or zero density scallop populations.

High mortalities of *A. ventricosus* juveniles could be attributed to different reasons, but since no studies have been conducted in the Archipelago on scallop diseases, predation, competition, food availability, and other factors that may affect them, it is not possible to determine with certainty the possible causes of these deaths. Further studies are suggested in order to identify the reasons for these high mortalities.

Through this study we also identified some fishery problems in the Las Perlas Archipelago. Population on the islands depends basically on fishing for their subsistence; as a consequence overfishing is likely to occur. It is necessary to create other job sources, such that the necessity for stock exploitation could be reduced. It is also necessary that government authorities put more effort in the compliance of fishery regulations such that overfishing could be avoided.

Studies have indicated that population natural recovery may take a decade or more and enhancement efforts are necessary to restore the stock. Our study indicated that no population recovery has occurred in Las Perlas Archipelago after almost two decades of collapse, however, Panama is putting efforts into increasing scallop stocks and repopulating natural banks through mariculture techniques.

6. REFERENCES

Aguilar M., & W.B. Stotz. 2000. Settlement Sites of Juvenile Scallops *Argopecten purpuratus* (Lamark, 1819) in the Subtidal Zone at Puerto Aldea, Tongoy Bay, Chile. J. Shellfish Res. 19: 749-755.

Ansell, A.D. 1974. Seasonal changes in biochemical composition of the bivalve *Chlamys septemradiata* from the Clyde Sea area. Mar. Biol. 25: 85-99

Arsenault, D. J. & J.G. Himmelman. 1996. Size-realted changes in vulnerability to predators and spatial refuges use by juvenile Iceland scallops *Chlamys islandica*. Mar. Ecol. Prog. Ser. 140: 115-122.

Asamblea Legislativa de Panamá. 1987. Gaceta Oficial. Decreto Numero 6.

Autoridad Marítima de Panamá. 1998. Dirección de Planificación y Desarrollo del Sector Marítimo. Departamento de Estadísticas Generales. Compendio Estadístico 1998.

Barber, B.J. & N.L. Blake. 1983. Growth and reproduction of the bay scallop *Argopecten irradians* (Lamarck) at its southern distributional limit. J. Exp. Mar. Biol. Ecol. 66: 247-256

Bryant P.J. 2000. Fish and Fisheries. Biodiversity and Conservation: A Hypertext Book. http://darwin.bio.uci.edu/~sustain/bio65/lec04/b65lec04.htm#top

D´Croz L., Del Rosario J & Gomez J. 1991. Upwealling and phytoplankton in the Bay of Panama. Rev. Biol.. Trop., 39 (2): 233-241.

D´Croz L. & Robertson R.R. 1997. Coastal Oceanographic Conditions Affecting Coral Reefs on both sides of the Isthmus of Panama. Proc. 8th Int. Coral Reef Sym. 2: 2053-2058.

D´Croz L., Mate L. & Oke J.2001. Responses to Elevated Sea water Temperatures and UV radiations in the Coral Porite Lobata from upwelling and non-upwealling environment on the Pacific Coast of Panama. Bulletin of Marine Science.

D´Croz L., Kwiecinski B.,Mate J., Gomez J. & Del Rosario J. 2003. El Afloramiento Costero y el Fenómeno de el Niño: Implicaciones sobre los Recursos Biológicos Del Pacifico de Panama. Tecnociencia. 5: 35-49

Dirección General de Recursos Marinos. 1992. Estadísticas Pesqueras:1981 –1991.

Dirección General de Recursos Marinos. 2004. Producción Pesquera Nacional, Según Actividad y Grupo de Especie: 1999 – 2003.

Ekman, J. E. 1987. The roel of hydrodinamics in recruitment, growth and survival of *Argopecten irradians* (L.) and Anomia simplex (D Orbigny) with eelgrass meadows. J. Exp. Mar. Biol.. Ecol. 106: 165-191.

Felix-Pico, E., A.Tripp- Quezada & J. Singh-Cabanillas. 1989. Antecedentes en el cultivo de Argopecten circularis(Sowerby) en Baja California Sur, México. Inv. Mar. CICIMAR 4: 75-92.

Forsberg, E. 1969. On the climatology, oceanography and fisheries of the Panama Bight. Inter-American Tropical Tuna Commission. 14: 385 pp.

Foster N. 1997. The Molluscan Fisheries of Alaska. In C.L. Mackenzie, Jr., A Rosenfield, and W.L. Hobart(Editors), The history, present conditions, and future of the molluscan fisheries of North and Central America and Europe. 2:131-144.US. Dep. Commer., NOAA Tech Rep. NMFS128.

Glynn P.W. 1972. Observation on the ecology of the Caribbean and the Pacific coast of Panama. In: Jones ML (ed) The Panmic biota: some observation prior ro a sea-level canal. Bull. Biol. Soc Wash, Washington. 2: 13:30.

Guerra-Lima Z.I., Mazon-Suastegui., J.M.,Vergara-Lopez P., Robles-Mungaray M., Osuna-GarciaM., Morales-Rodriguez., Conte-Diaz H., Sainz-Mendez I., and V. Cerrud-Linares. 2002. Avances en la producción de Conchuela Argopecten ventricosus(circularis) en la Republica de Panama. Ministerio de Desarrollo Agropecuario de la Republica de Panama.

Keen, A. M. 1971. Sea shells of tropical West America. Standford University Press. Second Edition. Standford, California. U.S.A. 208 pp.

Marelli D.C., W.S. Arnold & C. Bray. 1999. Levels of Recruitment and Adult Abundance in a Collapsed Population of Bay Scallops (*Argopecten irradians*) in Florida. J.Shellfish Res. 18: 393-399.

Mazon-Suastegui., J.M., Guerra-Lima Z.I., Vergara-Lopez, P., Osuna-Garcia M., Robles-Mungaray, Morales-Rodriguez., Olivares-Paulette O and M. Moreno-Tuñon. 2004. Cultivo Experimental de Conchuela Argopecten Ventricosus en Farallón, Panama, a Partir semilla producida en el Laboratorio. Ministerio de Desarrollo Agropecuario, Panama.

Ministerio de Desarrollo Agropecuario. 2004.Bases technologicas para el cultivo de la Conchuela en la Republica de Panama.

Nadeau M. & Cliche G. 1998. Predation of Juvenile Sea Scallops (*Placopecten Magellanicus*) by Crabs (*Cancer Irroratus and Hyas*) and Starfish (Asterias vulgaris, Leptasterias Polaris, and Crossaster Papposus. J.Shellfish Res. 17: 905-910

Panamá en Cifras.2003. Dirección de estadísticas y Censo. Años 1998-2002.

Pohle, D. G., V.M. Bricelj & Z. Garcia-Esquivel. 1991. The eelgrass canopy: an above-bottom refuge from benthic predators for juvenile bay scallops Argopecten irradians. Mar. Ecol. Prog. Ser. 74: 47-59.

Quayle D.B. & Newkirk G.F. 1989. Farming Bivalve Molluscs: Methods for study and Development. Advance in World Aquaculture. 1: 1-294

Robinson A.M. 1997. Molluscan Fisheries in Oregon: Past, Present, and Future. In C. Mackenzie, Jr., A Rosenfield, and W.L. Hobart(Editors), The history, present conditions, and future of the molluscan fisheries of North and Central America and Europe. 2:131-144.US. Dep. Commer., NOAA Tech Rep. NMFS128.

Reynolds K.W. & T.M. Smith (1994) Improved global sea surface temperature analyses. J. Climate 7:929-948.

Roughgarden J. & Smith F. 1994. Why fisheries collapse and what to do about it. Proc. Natl. Acad. Sci. USA. 93: 5078-5083.

Santamaria N.A., E.F. Felix-Pico, J.L. Sanchez-Lizaso, J.R Palomarez-Garcia, & M. Mazon-Suastegui. 1999. Temporal coincidence of the Annual Eelgass *Zostera marina* and Juvenile Scallops Argopecten ventricosus (Sowerby II, 1842) in Bahia Concepcion, Mexico. J. Shellfish Res. 18: 415-418.

Sicard M.T., A.N. Maeda-Martinez, P. Ormart, T. Reynoso-Granados & L. Carvalho. 1999. Optimum Temperature for growth in the catharina Scallop (Argopecten ventricosus-circularis, Sowerby II, 1842). J. Shellfish Res.18: 385-392.

The Department of Primary Industries, Water & Environment. Comercial Scallop fishing. Sea Fishing and Aquaculture. http://www.dpiwe.tas.gov.au/inter.nsf/WebPages/ALIR-4YQ4EY?open

Tripp-Quezada, A 1985. Explotación y cultivo de la almeja catarina *Argopecten circularis* in Baja California Sur. Tesis de Maestria, CICIMAR-IPN, La Paz, B.C.S., México.

Villalaz J.R. & J.A. Gomez. 1997 The History, Present Condition, and the Future of the Molluscan Fisheries of Panama. 1997 . In C.L. Mackenzie, Jr., A Rosenfield, and W.L. Hobart(Editors), The history, present conditions, and future of the molluscan fisheries of North and Central America and Europe. 2:131-144.US. Dep. Commer., NOAA Tech Rep. NMFS128.

Villalaz J. 1992. Reproductive biology of *Argopecten circularis*. Univ. Del., Newark, Ph.D. thesis, 100p.

Villalaz J. 1994. Morphometric and biochemical changes in two age classes of the tropical scallop, *Argopecten ventricosus*, under laboratory conditions. American Malecology Bulletin. 11: 67-72

Wolff M., & E. Alarcon. 1993. Structure of a Scallop *Argopecten purpuratus* (Lamark, 1819) Dominated Subtidal Macro-invertebrate assemblage in Northern Chile. *J. Shellfish Res.* 12: 295-304.

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6. APPENDICES

Station	Lat.	Long	Depth (m)	Expedition	Date	# Argopecten
1	N 8 31 39	W 79 03 20	21.5	Artesanal	17/06/04	8 small , 23 big
2	N 8 31 19	W 79 03 22	9.5	Artesanal	17/06/04	few big
3	N 8 31 14	W 79 03 25	9	Artesanal	17/06/04	nothing
4	N 8 31 06	W 79 03 39	7	Artesanal	17/06/04	nothing
5	N 8 30 46	W 79 04 22	12	Artesanal	17/06/04	28 small
6	N 8 30 36	W 79 04 22	9.5	Artesanal	17/06/04	7 small
7	N 8 32 50	W 79 02 56	6	Artesanal	17/06/04	nothing
8	N 8 33 57	W 79 02 48	9	Artesanal	17/06/04	3 small, 1 big
9	N 8 34 19	W 79 00 40	12	Artesanal	17/06/04	20 small
10	N 8 34 12	W 79 03 45	10	Artesanal	17/06/04	
11	N 8 34 10	W 79 04 16	23	Artesanal	17/06/04	45 small, 5 big
12	N 8 34 29	W 79 04 22	18	Artesanal	17/06/04	32 small
13	N 8 21 35	W 78 58 09	18	Artesanal	17/06/04	
14	N 8 20 52	W 78 58 00	10	Artesanal	18/06/04	189 small
15	N 8 20 16	W 78 58 05	8	Artesanal	18/06/04	8 small
16	N 8 20 19	W 78 57 57	8	Artesanal	18/06/04	hundreds
17	N 8 24 10	W 79 00 10	10	Artesanal	18/06/04	few dozen
18	N 8 24 17	W 79 00 18	15	Artesanal	18/06/04	few dozen
19	N 8 24 32	W 79 00 44	15	Artesanal	18/06/04	few big
20	N 8 29 31	W 79 04 44	9	Artesanal	18/06/04	1 big
21	N 8 29 37	W 79 04 46	16	Artesanal	18/06/04	nothing
22	N 8 31 29	W 79 03 09	16	Artesanal	18/06/04	11 small, 8 big
23	N 8 31 23	W 79 03 12	13	Artesanal	18/06/04	nothing
24	N 8 31 38	W 79 00 28	13	Artesanal	18/06/04	1 medium
25	N 8 32 03	W 79 00 18	15	Artesanal	18/06/04	nothing
26	N 8 31 59	W 79 00 36	11	Artesanal	18/06/04	nothing
27	N 8 31 46	W 78 59 52	16	Artesanal	19/06/04	nothing
28	N 8 32 25	W 79 00 31	11	Artesanal	19/06/04	nothing
29	N 8 32 07	W 79 01 13	12	Artesanal	19/06/04	one small
30	N 8 31 59	W 79 01 30	15	Artesanal	19/06/04	few big (old), 2 small
31	N 8 31 57	W 79 01 37	15	Artesanal	19/06/04	1 old
32	N 8 30 25	W 79 03 53	12	Artesanal	19/06/04	nothing
33	N 8 30 07	W 79 04 12	12	Artesanal	19/06/04	5 small, 3 old
34	N 8 30 19	W 79 04 20	12	Artesanal	19/06/04	15 small
35	N 8 30 51	W 79 04 33	12	Artesanal	19/06/04	24 small, 2 big
36	N 8 31 22	W 79 04 08	12	Artesanal	19/06/04	25 small, 3 dozens adults
37	N 8 31 52	W 79 03 22	13	Artesanal	19/06/04	big (old) 3 dozens
38	N 8 31 09	W 79 03 15	8	Artesanal	19/06/04	nothing
39	N 8 31 00	W 79 03 20	8	Artesanal	19/06/04	nothing

Table 2. Results of A. ventricosus artesanal surveys

Est.	Lat.	Long	Depth (m)	Expedition	Date	Condition
18	N 8 19.50	W 78 47.71	32.0	Lessios	08/28/2000	live
29	N 8 19.26	W 79 06.91	17.7	Lessios	08/29/2000	live
2	N 8 14.22	W 78 53.52	13.5	Rachell	04/06/2004	live
12	N 8 13.13	W 78 51.69	27.2	Rachell	04/07/2004	live
20	N 8 15.13	W 78 46.27	27.0	Rachell	04/08/2004	live
41	N 8 14.77	W 78 04.40	20.3	Rachell	04/09/2004	live
46	N 8 14.94	W 79 05.62	16.2	Rachell	04/10/2004	live
47	N 8 14.88	W 79 06.07	10.6	Rachell	04/10/2004	live
48	N 8 10.87	W 79 05.33	16.3	Rachell	04/10/2004	live
51	N 8 15.03	W 79 05.68	12.6	Rachell	04/10/2004	live
55	N 8 14.73	W 79 05.25	15.0	Rachell	04/10/2004	live
56	N 8 14.67	W 79 05.22	17.4	Rachell	04/10/2004	live
59	N 8 21.02	W 79 04.94	21.5	Rachell	04/10/2004	live
64	N 826. 12	W 79 06.16	18.1	Rachell	04/11/2004	live
65	N 825.40	W 79 04.52	30.2	Rachell	04/11/2004	live
66	N 824.50	W 79 04.65	17.2	Rachell	04/11/2004	live
68	N 827.35	W 79 01.19	12.9	Rachell	04/11/2004	live

Table 3. Stations where live *A. ventricosus* were recorded by Smithsonian Cruises (Rachell and Lessios)

Station #	Darwin stations	Lat.	Long	Depth (m)	Expedition	Date	Condition
1	95	8 34.550 N	78 56.036 W	33.5	Darwin project	13/08/04	nothing
2	106	8 37.247 N	79 01.779 W	23.5	Darwin project	13/08/04	nothing
3	92	8 34.097 N	79 04.867 W	26.6	Darwin project	13/08/04	nothing
4	113	8 39.657 N	79 01.869 W	19.0	Darwin project	13/08/04	live
5	75	8 29.460 N	78 56.350 W	15.4	Darwin project	13/08/04	nothing
6	30	8 18.321 N	79 09.596 W	66.0	Darwin project	14/08/04	nothing
7	13	8 13.567 N	79 01.814 W	34.0	Darwin project	14/08/04	nothing
8	34	8 18.000 N	78 58.833 W	14.5	Darwin project	14/08/04	nothing
9	71	8 28.770 N	79 07.340 W	36.7	Darwin project	14/08/04	nothing
10	53	8 23.359 N	79 09.596 W	12.0	Darwin project	14/08/04	nothing
11	17	8 12.659 N	78 51.036 W	27.0	Darwin project	15/08/04	nothing
12	38	8 18.030 N	78 47.971 W	29.2	Darwin project	15/08/04	nothing
13	62	8 26.474 N	78 50.350 W	25.4	Darwin project	15/08/04	nothing

Table 4. Results of Darwin Project cruise survey.