Trends in Shrimp Catch in the Hypoxic Area of the Northern Gulf of Mexico

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Introduction

An effect of hypoxia on shrimp landings is expected, both through reducing catch in areas of high hypoxia and concentrating catches in adjacent areas. Investigations of seasonal hypoxia in Louisiana offshore reveal that infauna are killed and fish and shrimp are often sparse or absent (Rabalais and Harper, 1991 and 1992; Renaud, 1986). Comparison of hypoxic areas in the New York Bight and the northern Gulf of Mexico indicate similar reductions in abundance of infauna (Boesch and Rabalais, 1991). Although infauna typically recover during months without hypoxia, the community remains in an early successional state because of mortalities during the summer every year (Boesch and Rabalais, 1991). The affected area off of Louisiana is large, covering up to 9500 km^2 (Rabalais et al., 1991), which coincides with historical white shrimp (*Penaeus setiferus*) and brown shrimp (*P. aztecus*) fishing grounds (Lindner and Anderson, 1956; Christmas and Etzold, 1977). These shrimp rely upon benthic infaunal foods as the mainstay of their diets (McTigue and Zimmerman, 1991).

The National Marine Fisheries Service has a database on monthly shrimp landing statistics for the Gulf of Mexico going back to 1960. The database is used to follow shrimp landings trends and estimate shrimp trawling effort for management of penaeid shrimp resources in the federal Exclusive Economic Zone (EEZ). Subareas of reported landings and effort include historical areas of hypoxia and thus may be useful in comparisons of interrelationships. However, it must be recognized that the shrimp statistics database was not designed for detecting effects of hypoxia and reported subareas of landings may be undesirably large for ideal analysis. Notwithstanding this shortcoming, the number of data entries are relatively large and cover many years including the past decade when the area of hypoxia has been measured annually. With retrospective analysis, we may be able to observe trends that suggest relationships between shrimp landings or effort and the annual extent of hypoxia.

Methods

The data on shrimp landings are gathered by 21 port agents in major fishing ports from Key West to Brownsville (Figure 32; Poffenberger, 1991). These port agents canvas 450–500 dealers each month, record landings (a mandatory reporting requirement for the dealers) and assign landings to areas in a statistical grid system designed for the Gulf of Mexico (Figure 33). The statistical subareas are numbered and subdivided into depth zones in 5 fathom increments out to 25 fathoms and landings data is entered for each subarea by depth zone (Figure 34). This census of dealers provides information on the size of catch and the number of trips by area and depth. Some major ports for shrimp landings occur between Freeport, Texas and New Orleans, Louisiana and, not surprisingly, prominent shrimping subareas overlap with areas of seasonal hypoxia in the northwestern Gulf. In particular, statistical sub-areas 13, 14, 15, 16, and 17 incorporate waters offshore of Louisiana and uppermost Texas where hypoxia has been documented.

In order to establish catch-per-unit effort (CPUE), the port agents interview shrimp fishermen, collecting information on trip duration, time fished, and location fished (Figure 35). Since this reporting is not mandatory, the reliability of these data is dependent upon access to cooperative fishermen. A simple equation incorporating interview data and landings data is used to calculate shrimp fishing effort. Landings from the dealers divided by the CPUE from sample interviews is equivalent to effort, which is usually reported in days fished (Figure 36). CPUE is estimated in instances where landings have no associated interviews. At present, about 70% to 80% of the shrimp pounds landed have CPUE interview data and the other 20% to 30% is estimated (Figure 37 and 38).

To evaluate relationships between hypoxia, size-of-catch and CPUE, respective data in each statistical cell off the coast of Louisiana was calculated. A cell corresponds a depth zone with a subarea. For example, the cell closest to shore in subarea 17 is zero to 5 fathoms; the next cell offshore is 5 to 10 fathoms, and so on. Louisiana subareas are demarked longitudinally and depth zones are roughly latitudinal. We entered this information into our geographic information system program (GIS) and color-coded catch to represent average monthly pounds of shrimp landed during July and August each year. The color scale grades from gray, representing very little or no catch, to dark red, representing more than 600,000 pounds of shrimp tails. Intermediate values were represented by shades of orange. The average July and August catch in each statistical cell, months of high hypoxia, was determined for each year between 1985 and 1994 and entered into the GIS. Annual area of hypoxia was plotted from data reported by Rabalais et al. (1991, 1992 and unpublished). The hypoxic area was entered in the GIS, calculated for each statistical cell and superimposed on the image of mean July and August catch for each year. A step-wise regression with catch as the dependent variable and depth, subarea, East/West , years, and percent area of hypoxia in cells as independent variables was performed.

Results and Discussion

Hypoxia and July/August shrimp catch are depicted in Figures 39 through 45, presenting the years 1985, 1986, 1990, 1991, 1992, 1993 and 1994. Offshore hypoxia developed to greater or lesser extent every summer during this ten year period. A number of relationships were evident. Shrimp catch nearshore was always significantly higher than catch offshore regardless of the extent of hypoxia. In addition, a significant relationship in catch between subareas occurred from West to East across years. Catches were significantly higher near the Texas-Louisiana border compared to the Mississippi delta. This corresponds to the generalized distribution of hypoxia which is usually greater in the eastern sector compared to further west. But during years when area of hypoxia was large in the west, shrimp catch was diminished there too. Area and distribution of hypoxia between consecutive years often varied significantly as did overall shrimp catch. The year 1990, with less hypoxia, had higher catch than 1991, with greater hypoxia, including a large hypoxic area which coincided with a reduction in catch in the nearshore 5 fathom zone. During 1993, with hypoxia broadly distributed along the coastline, catch was high nearshore and markedly lower offshore. However, this relationship was not as strong during a similar large hypoxic event during 1994. The magnitude of catch (strength of the year class) was different between 1993 and 1994, but the pattern of catch distribution related to hypoxia remained similar.

Catch plotted against the percent area of hypoxia in each cell reveals a significant negative relationship. Importantly, CPUE plotted against percent area of hypoxia in cells demonstrates that CPUE does not change relative to area of hypoxia (Figure 46). The regression of catch against hypoxia is affected by an interaction of a significant relationship between catch and depth. The highest catches always occur nearshore in cells with a very low percentage of hypoxia area. In cells with a very high percentage of hypoxia, we never observe high catch despite similar CPUEs. This is interpreted as meaning that shrimp fishermen do not trawl in those areas within a cell that have high hypoxia. Converting the data to catch per unit hectare demonstrates the same relationship (Figure 47). However, we also observed low catches in offshore cells with low hypoxia, i.e., the relationship of diminution in catch from nearshore to offshore corresponding to increasing depth.

There was a negative, albeit not always significant, relationship between shrimp catch and area of hypoxia. This may have very important historical implications for the Louisiana shrimp fishery. The traditional inshore and nearshore fishery appears to be promoted and the offshore fishery is discouraged by hypoxia. Catches in offshore waters beyond the hypoxic area are always as low as those in the hypoxic area. High catches nearshore are always in cells with low hypoxia. The interpretation is that the large hypoxic area in intermediate depth zones concentrates shrimp nearshore. This is supported by laboratory evidence that shrimp move away from low oxygen water (Renaud, 1986a) and field evidence of low densities (Renaud, 1986b). Moreover, the phenomena of concentration of nekton avoiding hypoxia in other areas, the so-called jubilees in Mobile Bay, has been known for years (Loesch, 1960). Since shrimp seem to avoid hypoxia, the hypoxic area would effectively block a large part of the population from moving offshore. This blocking phenomena may in part explain persistent low catches in offshore Louisiana beyond the hypoxic zone. Moreover, since CPUE doesn't change relative to percent hypoxia in statistical cells, we take this as evidence that shrimpers do not trawl in unproductive waters, and that waters offshore of the hypoxic zone are indeed unproductive. More simply stated, it is economic reality that as the shrimp move so do the shrimp fishermen and those who do not catch anything in their trawls move on in order to profit. Thus, wherever shrimp fishermen chose to stay and trawl their CPUE is relatively high. The statistical cells with low catch associated with hypoxia and offshore waters beyond mean that shrimpers are actively avoiding these areas. By contrast, higher catches occur in comparable offshore depth contours in Texas where hypoxia does not exist. Indeed, Texas has a very well developed offshore shrimp fishery. An alternative hypothesis is that the shrimp industry in Louisiana developed around white shrimp which is an inshore and nearshore species, and Louisianans did not build vessels big enough to trawl offshore whereas, the Texas shrimp industry developed around brown shrimp which is more an offshore species.

Although the landings data are coarse for the purpose and analyses would benefit from a specifically designed study, evidence of a negative relationship between hypoxia and shrimp catch appears to exist. Overall, offshore areas of extensive hypoxia during the summer months yield lower shrimp catches in July and August than nearshore areas with less hypoxia. Importantly, the shrimp appear to concentrate in shallow waters near shore between the hypoxic zone and the shoreline and the effect of diminished catch extends offshore well beyond the hypoxic zone.

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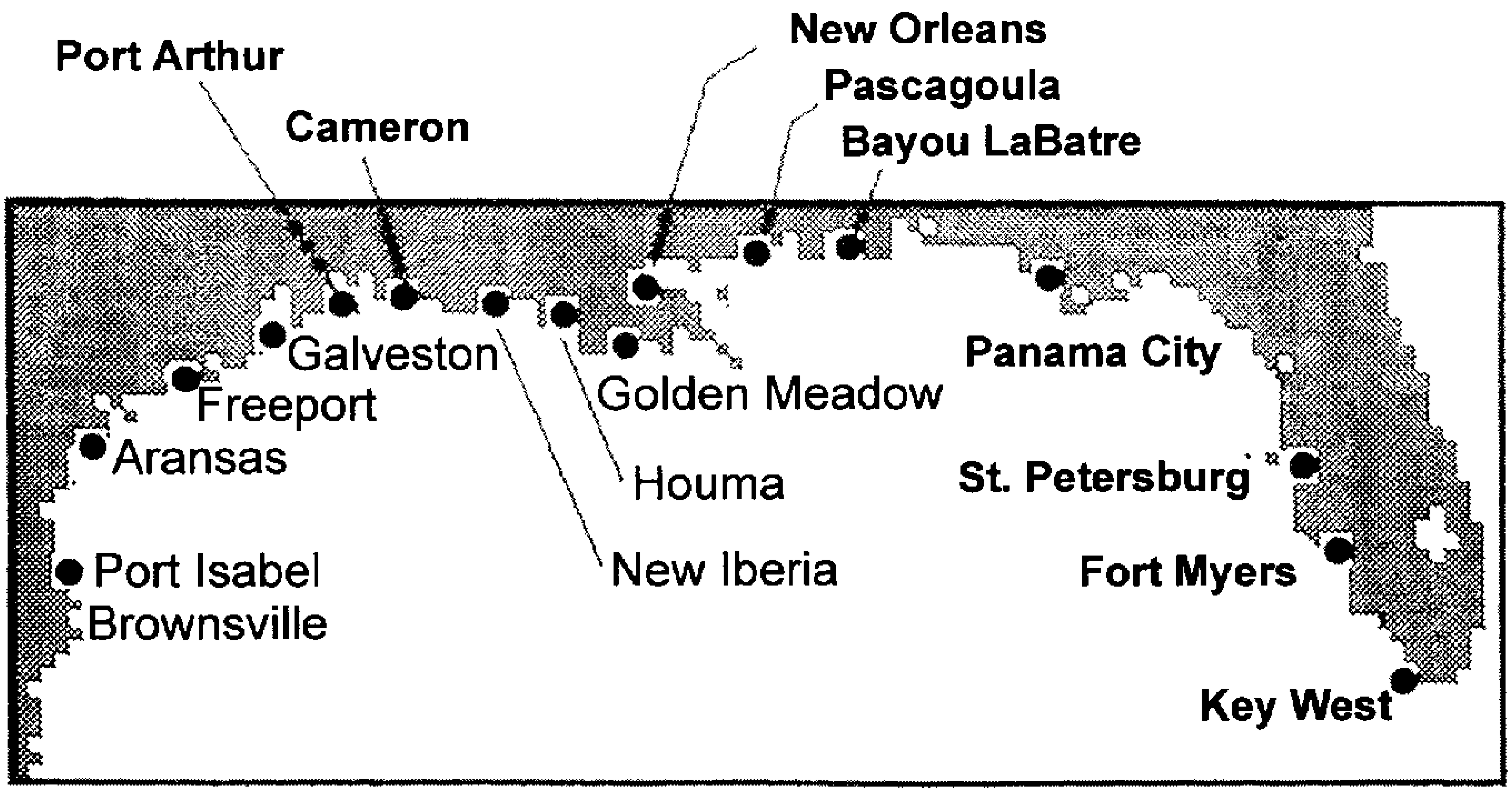


Figure 32.
Port Agents.

Landings Data

- Canvass between 450–500 dealers each month
- Record landings by trip
- Assign grid zones
- A census of catch and trips

Figure 33.

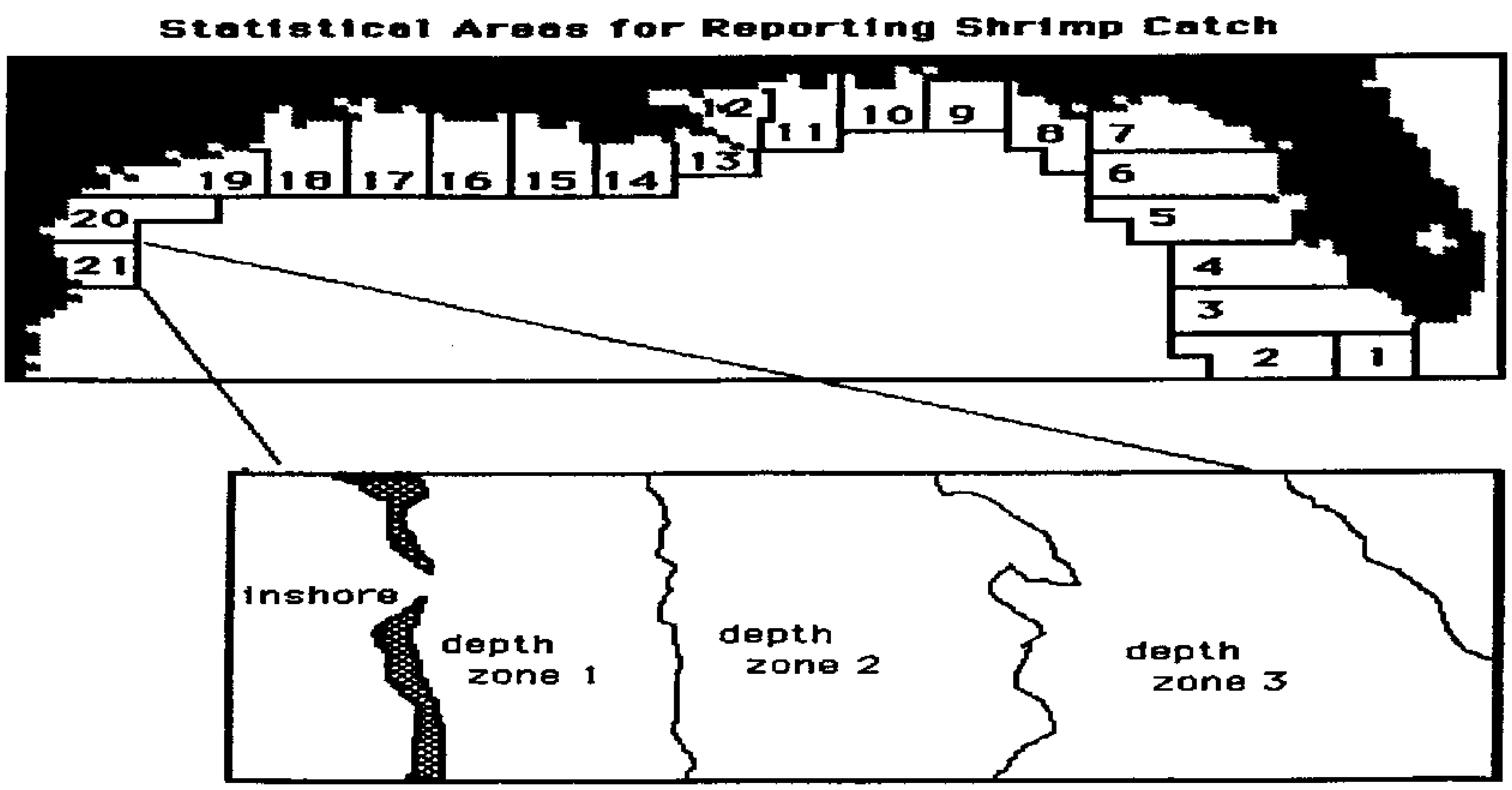


Figure 34.

CPUE Data

- Interview
- Data Items
  - Trip duration
  - Time actually fished
  - Area fished
- A census of catch and trips

Figure 35.

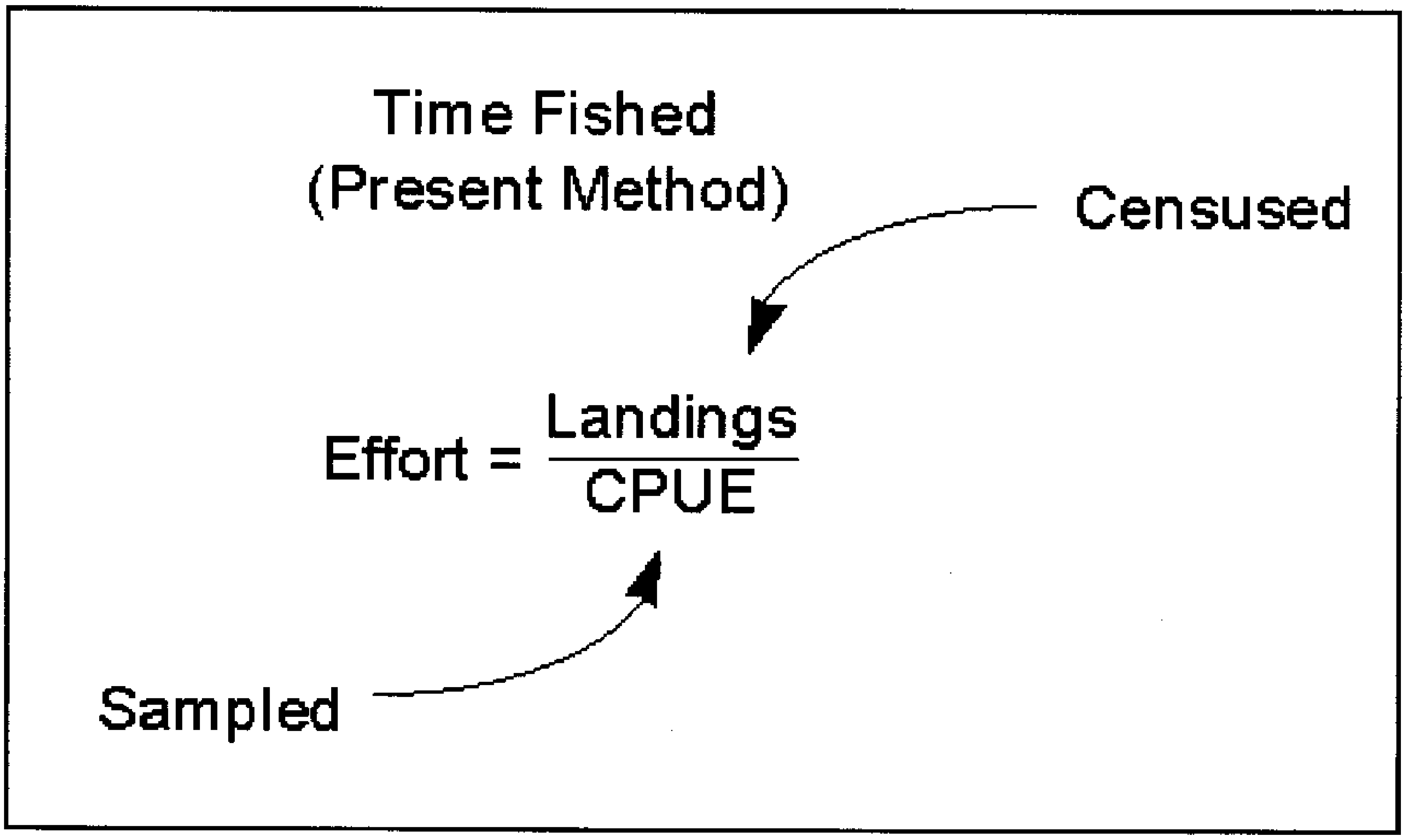


Figure 36.

Cells With Current Interview Data

- 70–80% of the shrimp pounds have an average CPUE associated with them
- What about the other 20–30% of the pounds?

Figure 37.

- Statistical model used to estimate the current CPUE (one model/month)
- $\log CPUE_{(ij)} = \mu_{(ij)} + year_{(i)} + location_{(j)} + \epsilon_{(ij)}$

Figure 38.

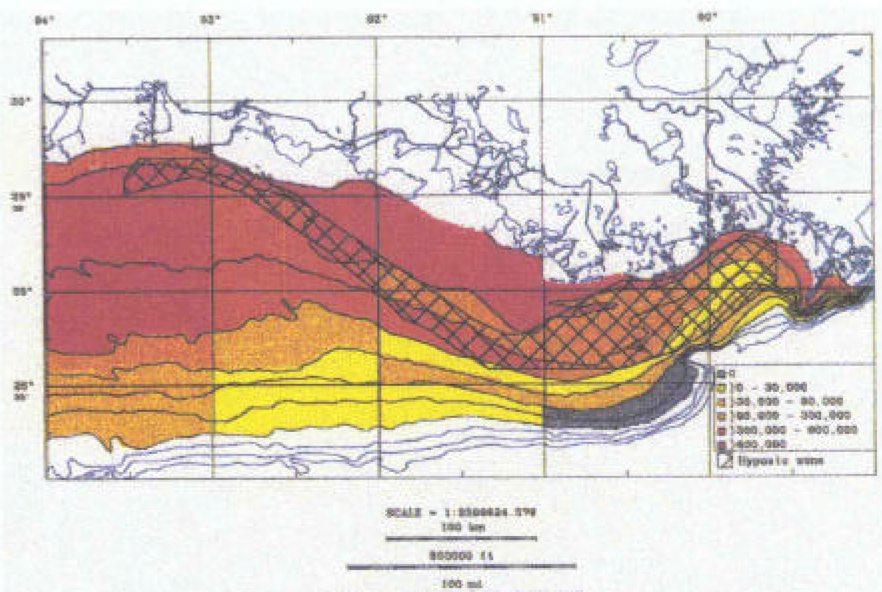


Figure 39.
Total Shrimp Catch (pounds)
July/August 1985

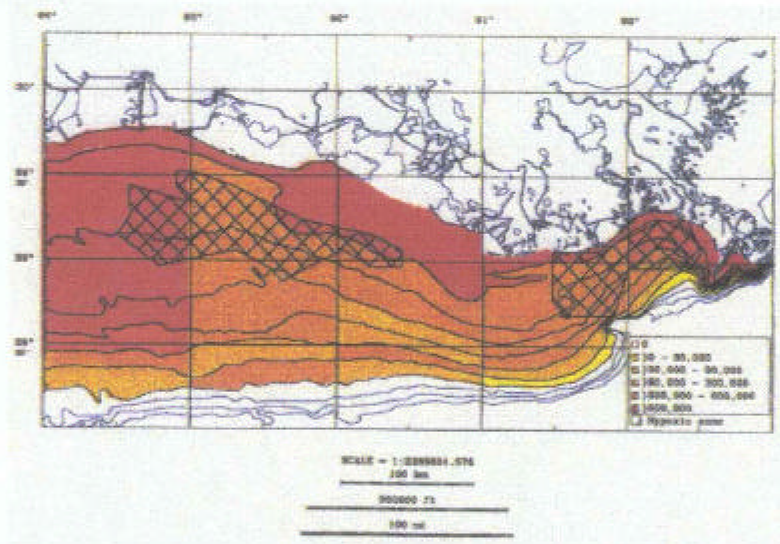


Figure 40.
Total Shrimp Catch (pounds)
July/August 1986

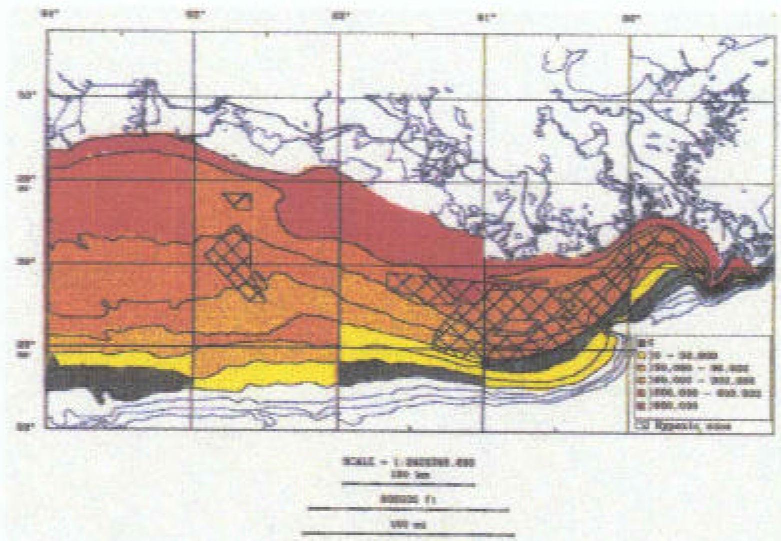


Figure 41.
Total Shrimp Catch (pounds)
July/August 1990

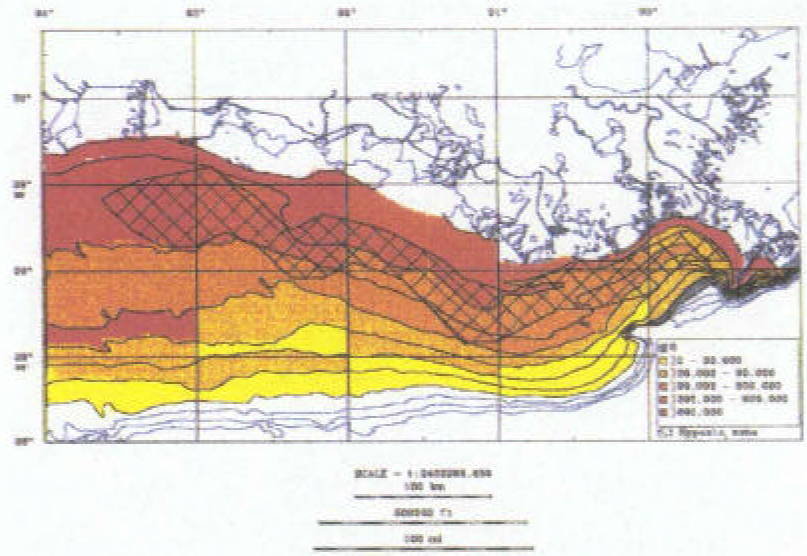


Figure 42.
Total Shrimp Catch (pounds)
July/August 1991

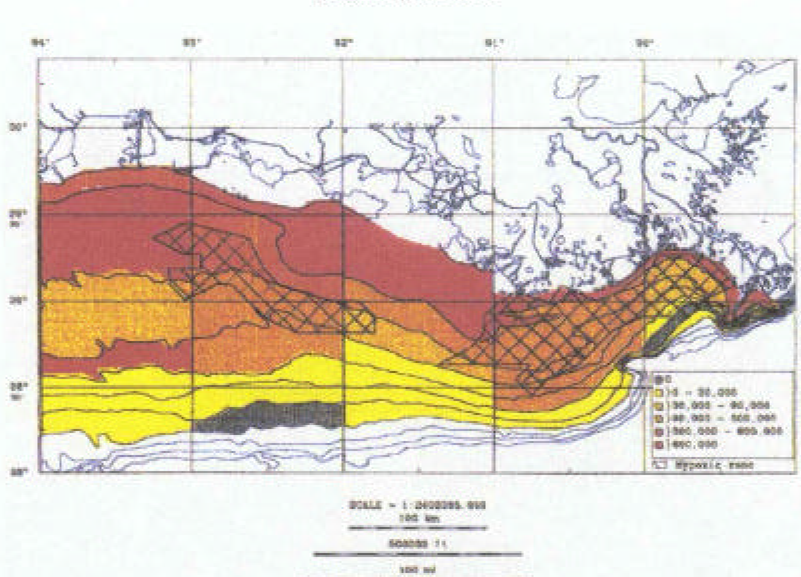


Figure 43.
Total Shrimp Catch (pounds)
July/August 1992

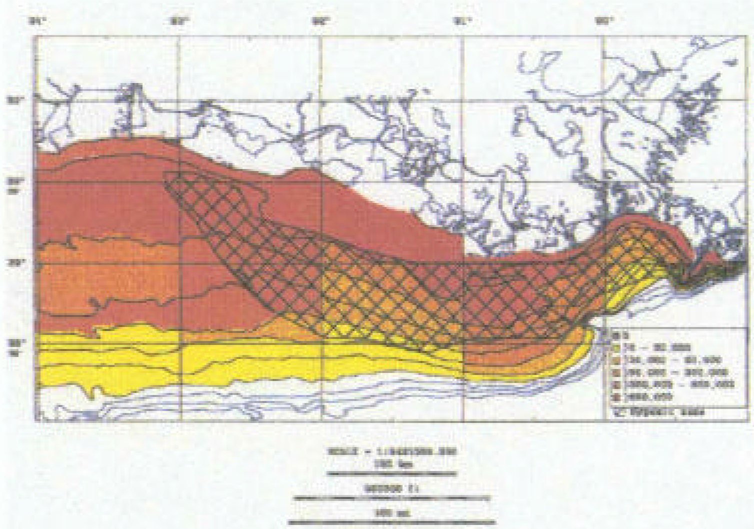


Figure 44.
Total Shrimp Catch (pounds)
July/August 1993

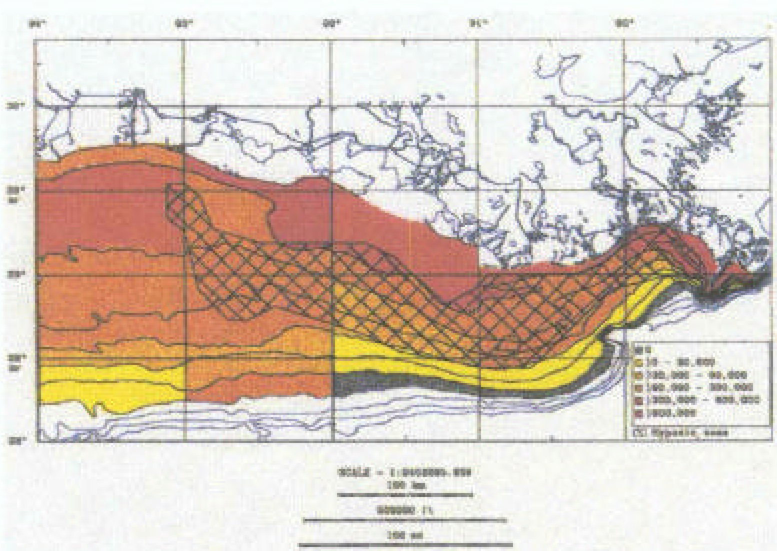
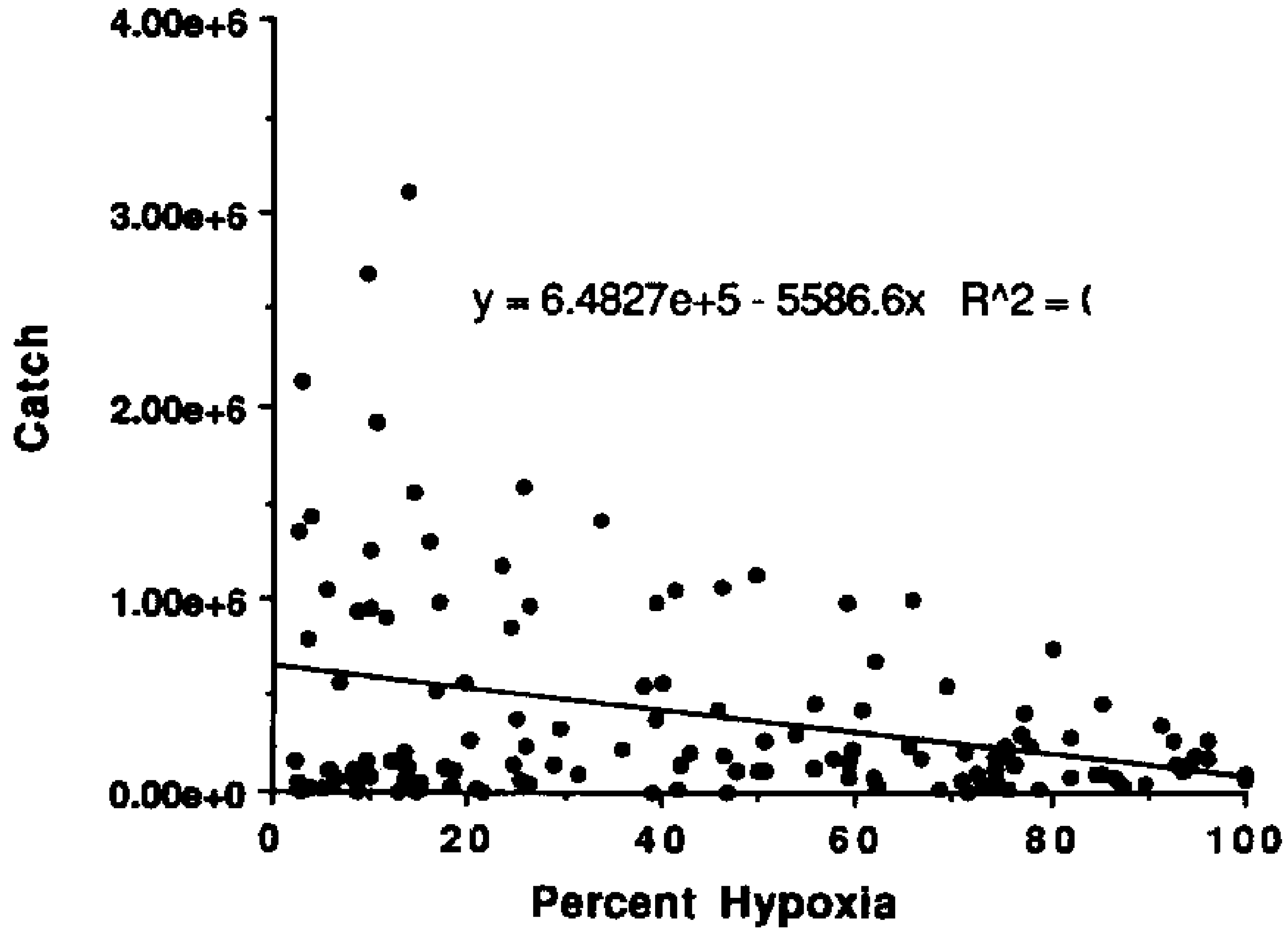


Figure 45.
Total Shrimp Catch (pounds)
July/August 1994



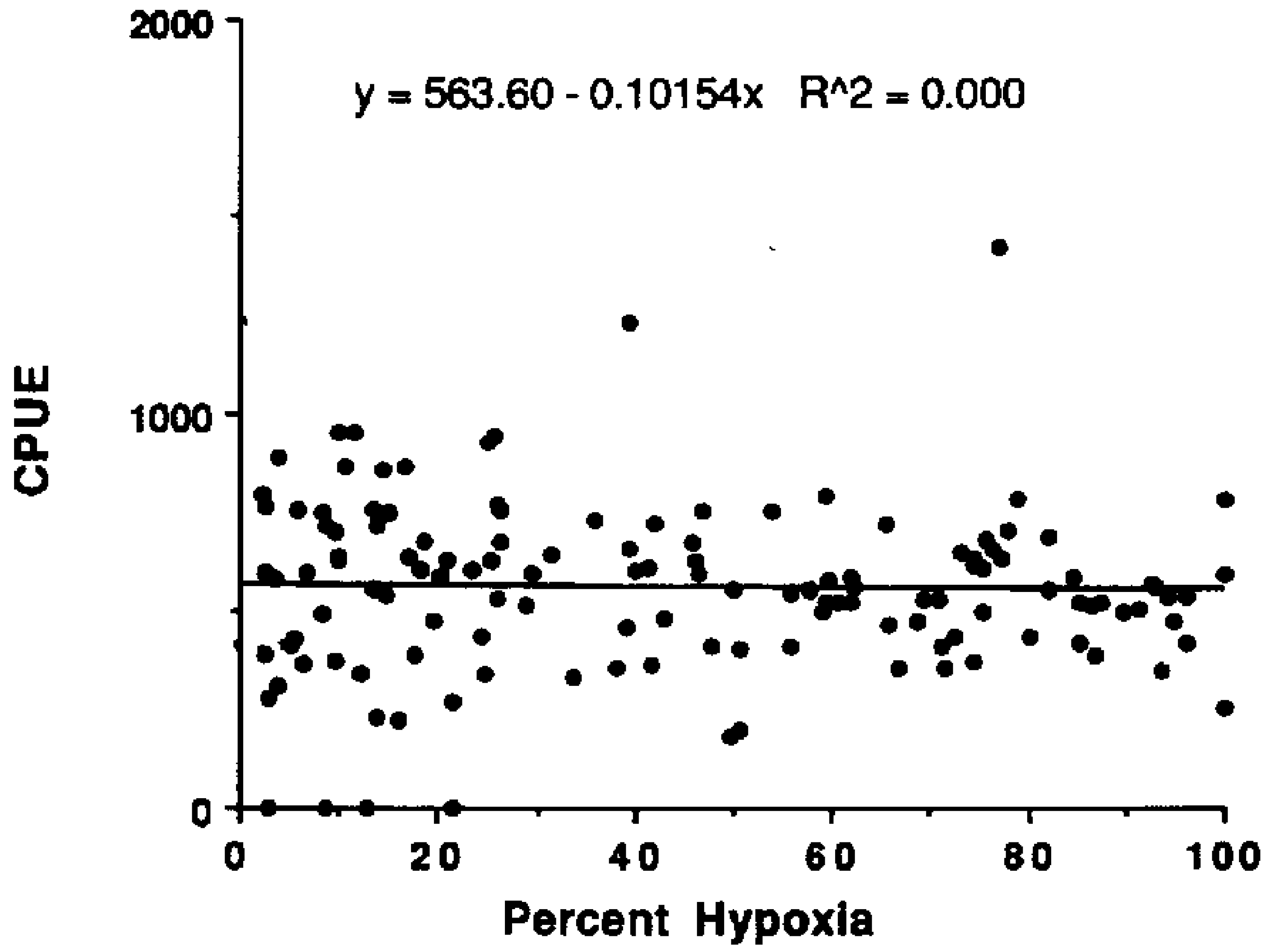


Figure 46.

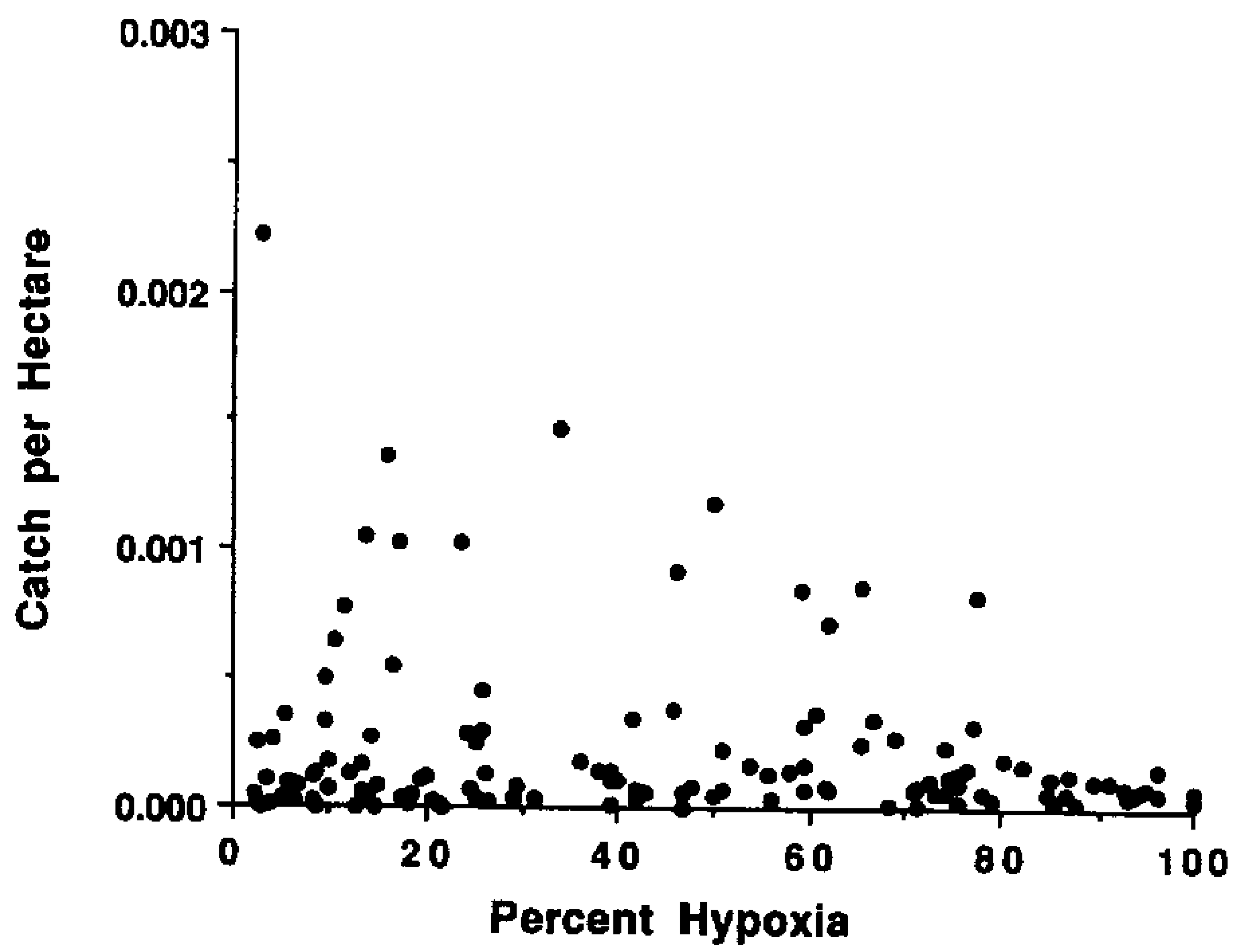


Figure 47.

Pesentation Discussion

Roger Zimmerman (NMFS—Galveston, TX)

Bob Anderson *(The Advocate—Baton Rouge, LA)* asked Roger Zimmerman if anyone had looked at the total shrimp catch per year during the years when there is a large hypoxia zone present.

Roger Zimmerman answered that although there appeared to be a very weak relationship between years, when he performed a step-wise regressional analysis, he could not demonstrate a strong relationship.

Eddie Funderberg *(Louisiana State University Agricultural Center—Baton Rouge, LA)* commented that the shrimp catch in cells of Zimmerman's map with 80 to 100 percent hypoxia appeared to be as good as in cells of zero percent hypoxia. In light of that data, he asked Roger Zimmerman to elaborate on his comment that the catch per unit effort (CPUE) did not vary because fishermen were not fishing in the area of hypoxia.

Roger Zimmerman responded that even in cells of 100 percent hypoxia there may be areas or times that the hypoxia fluctuates. If the hypoxia is absent and shrimp, which are very mobile move in, then it is possible to have a catch in those cells that have been identified as 100 percent hypoxic. Also, some of those cells are only 60 percent hypoxic. The shrimping activity in that cell is averaged over the whole cell. Unfortunately, there is no ability to separate within a cell.

Don Boesch *(University of Maryland— Cambridge, MD)* asked if the inability to catch shrimp in hypoxic waters was a result of a reduction in the shrimp population, or a decreased ability to catch that population. He also asked if Roger Zimmerman had an approach or strategy to study this question with either existing data or new observations.

Roger Zimmerman felt that there were two potential possibilities.

- The first possibility was a correlation between catch data and depth. That relationship could be analyzed by comparing shrimp catches in the 1960's to the nearshore and offshore abundances of shrimp. Hopefully, that would demonstrate that during periods of hypoxia there would be a reduced number of shrimp or a lower percentage of catch relative to near shore.
- The second, and most likely possibility is that the hypoxic zone could be causing the shrimp to migrate up against the shoreline.

William Wiseman *(Louisiana State University—Baton Rouge, LA)* asked if the data presented had been normalized. For example, shrimping activity in Louisiana, is basically localized in the nearshore. It is not considered an offshore fishery. Therefore, comparing the data to shrimping activity in Texas may be inconclusive, because the effort may be distributed differently.

From the research he has conducted on shrimp populations in Louisiana, environmental factors in the spring, (i.e., water temperatures and salinity regimes) have a great deal of influence on what production is going to be and what kind of recruitment we have in late spring and early summer. The fact that hypoxia does not really set up offshore during the spawning and larval migration periods inshore does not seem to be an influence. The ultimate growth and survival of juveniles, which is really dependent upon inshore conditions, does not seem to be affected either.

Roger Zimmerman confirmed that the data have been normalized by effort. He agreed with William Wiseman that the strength of the year class is more dependent upon the conditions in the nursery and inshore than it is in the offshore conditions. He thought they might be just redistributing the year class. It is possible to argue that as the organisms grow and move offshore as sub-adults, and if there is a large hypoxic zone where all the worms are dead, the feeding ground has obviously been impacted. It is similar to lower salinity impacts in the estuaries, which could reduce production in certain parts of the nursery. It is possible that the offshore feeding ground is being eliminated and that could affect growth rates.