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Changes among Ohio River fish populations due to water quality improvements and high-lift dams

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Changes Among Ohio River Fish Populations Due to Water Quality Improvements and High-Lift Dams

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TABLE OF CONTENTS

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ABSTRACT

Fish populations in the Ohio River have been monitored extensively by the Ohio River Valley Water Sanitation Commission (ORSANCO), along with state and Federal agencies, for over 40 years. The population data, collected via lock chamber rotenone surveys, showed that many species of Ohio River fish have demonstrated marked increases in abundance since these studies began. These trends in population density, both gradual and sharp, are likely associated with water quality improvements and the construction of high-lift dams. Pearson-r correlation through linear regression analyses showed 23 species or 42% of populations examined exhibit significant density increases from 1957 to 1998. An additional 27 species or 49% of those examined show distinct peaks in abundance by way of polynomial regression analyses. These trends were further revealed when population data was separated into three river sections (upper, middle, and lower). In all, 25 species or 89% demonstrated a significant density increase in one or more of the river sections. Such gradual increases in density are possibly related to improvements in water quality. These trends closely parallel changes induced by the Clean Water Act, 1972, which strengthened the control of waters discharged into the river. Also, 27 species or 100% were found to have undergone a significant peak in density in one or more of the river sections during the period of data collection. These "spikes" in fish density mirror increases in resource availability as high-lift dams expanded the water in the river channel. Percent family composition of groups showing both gradual density increases and density peaks were dominated by sunfishes (family Centrarchidae), minnows (family Cyprinidae), catfishes (family Ictaluridae), and suckers (family Catostomidae)—populations which may respond quickly to such habitat changes and reflect a more favorable environment.

INTRODUCTION

For over a century, the Ohio River has represented one of the most dynamic waterways in the United States. Called "la Belle Riviere" by early French settlers, the Ohio River once flowed naturally as a diverse and healthy lotic system; the ichthyofauna found there was highly prized for angling (Krumholz, 1981; Frost and Mitsch, 1989). However, inevitable changes to the river occurred as a result of man's ever-expanding settlement in the Ohio Valley. Initially, degradation to the Ohio was by way of logging, agriculture, mining and sewage (Taylor, 1989). Yet, as environmentally destructive as these activities were, notable changes among fish assemblages did not occur until the construction of the first dams. Designed to increase the navigational depth of the channel, these low-head dams were built from 1885 to 1927, and numbered fifty along the river's reach (Pearson and Pearson, 1989). A decline in small stream fishes was offset by a proliferation of large river species as all populations acclimated to the new environment.

The next transitional period in the Ohio's history was brought about by the heavy pollution and waste loading that were a product of the industrial boom. It was during this time span, 1930-34, that water quality was at its worst. Gradually, improvements to water quality were attained via installation of primary and secondary sewage treatment plants along with new standards to control industrial pollution in the river. Subsequently, a shift in fish species composition occurred as pollution tolerant species were replaced by more pollution intolerant species (Cavanaugh and Mitsch, 1989). However, these improvements were succeeded by the further enhancement of water quality through the Clean Water Act of 1972, and the construction of new high-lift dams.

The effect of water quality improvements, especially those related to dissolved oxygen, pH, and total and dissolved metals, on fish populations is well established. Fishes of the Ohio, being studied more extensively than those of any other waterway, are no different (Krumholz, 1981). Since the passage of the Clean Water Act (1972) and the further restriction of toxic substances discharged, many Ohio River fish species have shown a distinct increase in abundance. The objectives of this study, in terms of the response of fishes to water quality improvements, were: ① to determine the species that demonstrate a river-wide, positive temporal/density correlation, particularly focusing on populations that exhibit density increases after 1972; ② to examine differences in fish densities among the three major river sections; and ③ propose a plausible explanation for these changes and differences.

High-lift dams also represent a major influence in the growth and productivity of fish populations on large rivers. Once viewed as cataclysmic events that interrupt and alter most of a river's important ecological processes, recent studies show that most fish populations are able to grow and spawn under the new regimes created by these dams (Ligon et al., 1995; Liu and Yu, 1992). In addition, some populations may undergo a rapid increase in abundance initially or shortly after the high-lift dams are placed into operation. This is likely due to the introduction of streamside vegetation and other substrata into the channel once the water level is elevated. When presented with an unlimited environment—one conducive to feeding, refuge, and reproduction—populations tend to expand geometrically (Smith, 1996). Although such growth is not often sustainable as resources are depleted, many species are able to maintain a relatively higher density after this change.

The study objectives in regard to changes resulting from the construction of high-lift dams were: ① to determine the species which show a distinct "spike" in density initially or shortly after high-lift dams were placed into operation; and ② to analyze these peaks in density according to major river section and species type, concentrating on those species which are likely to respond favorably to the new environmental conditions created by high-lift dams.

REVIEW OF THE LITERATURE

The Historical Ohio River

Records of the ichthyofauna found in the Ohio River have been kept since the mid-18th century. These records reveal a great transition among fish populations from past to present as well as in various river sections (Krumholz, 1981). Pearson and Pearson (1989) discussed these changes in terms of pollution tolerance, stating that a growth in pollution tolerant species, following a period of water quality degradation, has been succeeded by an increase in pollution intolerant species after certain water quality improvements. Furthermore, they suggested the reintroduction of some native fishes that were eliminated during the time of heavy pollution. Cavanaugh and Mitsch (1989) also examined water quality trends in the Ohio, particularly those in the upper river. Once being the most industrialized and heavily polluted river segment, they reported a general improvement in water quality. They specifically noted a reduction in the concentrations of metal and cyanide. However, the conversion to a completely different habitat type occurred as the first dams were constructed. Designed to increase the navigational depth, both low-head and high-lift dams altered the resemblance of the present-day river from its free-flowing ancestor (Taylor, 1989).

Water Quality and Fishes

Although the habitats in which fishes live are continually changing, the parameters of temperature and light penetration are especially important in the dynamics of aquatic ecosystems (Lagler et al., 1977). Liu and Yu (1992) associated an increase in transparency with a growth in plankton biomass and primary production. They also found the initial population of planktivorous fish to be small, yet growing. However, other changes in water quality may have more harmful impacts on resident fish populations. Welcomme (1985) stated that pollution may affect aquatic life in three main ways: ① as lethal toxicity which kills fish at some point; ② as sub-lethal effects to behavior, growth, and disease resistance; and ③ as cumulative effects which may render fish unsafe for consumption. In the Ohio River, the impact of such pollution may be evidenced by extirpation of certain species. Pearson and Pearson (1989) found that nineteen of 159 known species reported from the Ohio have not been reported since 1970. Species diversity may also be influenced by pollution, as was found in three auxiliary chamber studies in the late 1950s. From 1957 to 1959, only nine species were collected from three sampling events at the Montgomery Lock and Dam. The collections were dominated by pollution tolerant species of small size—one collection of 480 fish weighed only 9lbs (ORSANCO, 1962). Yet, recent water quality improvements have clearly enhanced population growth and species diversity as 20 present-day Ohio River fish species have only been reported since 1970 (Pearson and Pearson, 1989).

Dams and Fishes

In an attempt to identify the ecological effects of dams from a geomorphic perspective, Ligon et al. (1995) stated that dams can alter a river's most important ecological processes. These changes include impacts to the flow of water, sediments, nutrients, energy, and biota. They have also presented problems in water allocation to the natural ecosystems as the demands of human societies have heightened (Petts, 1996). However, the most significant complications associated with dams and all aquatic organisms with habitat-specific requirements for a lotic environment are those related to temperature regimes and fish migration. Kriz (2000) stated that the Snake River dams, built in the 1960s and '70s, have transformed the once-wild river into a series of slack-water pools. These dams are likely the major factor contributing to the decline of native salmon. Likewise, a study by Nicola et al. (1996) on dams along the large rivers of Spain found all anadromous and catadromous fishes to be threatened; with species of eel, lamprey, sturgeon, and shad found to be extinct in wide areas. In a study of fish communities in the Murray-Darling river system in Australia, Gehrke et al. (1995) found a significant ($p < 0.005$) reduction in species diversity in regulated catchments. Here, river regulation is attributed to altering the relative abundance of native and alien fish via desynchronizing of environmental cycles and the reproductive cycles of the native species. In contrast, many pre-/post-impoundment studies of river fishes showed that the majority of species are not seriously affected. Even though the composition and percentage of frequency of species in the community may be different, the dam may not radically alter the thermal or hydrological regimes of the river (Ruiz, 1988). Moreover, much of the shift in species composition may be by virtue of the elimination of small stream species. De Jalon et al. (1994) found similar results in a study on the effects of a hydropower impoundment on macrophyte, macroinvertebrate, and fish communities in Rio Tera, Spain. A significant change to the community occurred through the loss of all cyprinids, along with most macrophytes and macroinvertebrates, but was offset by the persistence of salmonids. An additional study of fish assemblages in the River Svratka, Czech Republic, revealed a fish community formerly dominated by barbel was replaced by trout. This was possible by the release of water from the hypolimnion to induce changes to the temperature regimes (Penaz et al., 1999). In the Vltava River, Czech Republic, dams and pollution regulation were found to be the major influences in fish density increases (Kubecka and Vostradovsky, 1995). Other advantageous conditions created by dams include a reduction in suspended solids due to the "settling-effect" of the low-velocity pools. Bonacci et al. (1992), in a study of the lower Drava River, found a significant decrease in suspended sediment by 2.5 times due to the construction of a hydroelectric facility. They also state a 25% decrease in the transport of suspended sediment caused by the construction of the Varazdin impoundment. The reduction of such sediment from the water column can promote an increase in plankton biomass (Liu and Yu, 1992), which affords some fish an additional food source.

DESCRIPTION OF STUDY AREA

The Ohio River originates at Pittsburgh, Pennsylvania with the confluence of the Allegheny and Monongahela rivers. Flowing southwest for 1,578km (981mi.), the Ohio River drains into the Mississippi River at Cairo, Illinois (Fig. 1). It is the eleventh largest river in the United States and the greatest of all the Mississippi River's tributaries. Having a basin of 528,000km^2 (204,000mi^2) that covers fourteen states, it drains nearly seven percent of the United States' land area and is inhabited by ten percent of the U.S. population. It also serves as a partial political border for five states.

The once-wild Ohio River (Fig. 2) was originally impounded by fifty low-head navigational dams which have since been replaced by twenty high-lift navigational dams; the lock chambers, in which data for this study were collected, are part of the 20 high-lift dams. These dams maintain a minimum nine-foot navigational depth (Frost and Mitsch, 1989); they also create an average depth of nearly 24 feet (ORSANCO, 1994). The average width of the river is approximately 1,948 ft. and average flow is 14.4 cfs.

MATERIALS AND METHODS

Lock Chamber Surveys

From 1957 to 1997, the lock chambers of each of the twenty high-lift navigational dams and many of the fifty original low-head dams were sampled 341 times. Sampling involved the emulsification of an ichthyocide, rotenone (derived from Derris root), into the lock chamber's water through the wake of outboard boat motors. Rotenone surveys in lock chambers are considered ideal for estimating fish density due to the susceptibility of all fish to the effects of rotenone—albeit some are more susceptible than others—and the fixed area of the lock chambers (Krumholz, 1981). These lock chambers were left open downstream to permit fish occupancy and minimize the volume of water treated. After a concentration of 0.5-1ppm was achieved, surfacing fish, which were in respiratory paralysis, were netted and placed in tubs. The fish were then taken to the shoreline where they were sorted to species, weighed, and measured.

The Database

Data from these collections were provided by ORSANCO in the form of a Microsoft® Access database. However, conversions of the database into a Microsoft® Excel spreadsheet and into STATISTICA™ were required for the statistical analyses.

Data Organization

Data collected in this study were analyzed in an attempt to reveal trends in density among Ohio River fish populations. Initially, two-dimensional scatterplots were made of each of the 127 species collected in the lock chamber surveys. The purpose of these scatterplots was to graphically illustrate any temporal density correlation and those related to river mile. This led to categorization of the species into five groups: ① species with fewer than 30 individuals represented in the lock chamber collections; ② species which were collected sporadically or show no clear abundance trends; ③ hybrid and/or exotic species; ④ species which demonstrate a gradual change in abundance, either positive or negative, river-wide or in at least one river section; and ⑤ species that exhibit a sharp density increase over a brief time interval. With few exceptions, species placed into the first three groups were not considered in this study. Species with fewer than 30 representatives in a forty-year study could not be equitably compared to those with over 800,000 individuals collected, and may be considered to have an inconsequential role in the river system (Fig. 3). Species sporadically collected or those demonstrating no trends in abundance were often undergoing normal fluctuations in density associated with the environment's carrying capacity (Fig. 4). Lastly, hybrids and exotics were not examined because they often demonstrate unrealistic changes in density as they exploit unfilled niches or competitively exclude native species from allocation of resources (Fig. 5). However, 55 species representing either of the two remaining groups were analyzed according to abundance trends.

Defining the River Sections

The 981-mile reach of the Ohio River was divided into three river sections (Table 1). This was done to account for any water quality changes associated with river mile that might influence fish density—since the upper river was once more polluted than the remainder of the river—and to document the full effects of the high-lift dams, which were usually constructed in series within the river sections. Also taken into account were the location of the original fifty low-head dams.

Pearson-r Correlation and Linear Regression Analysis

The objective of correlation analyses is to determine the proportionality or relationship between an independent variable and a dependent or criterion variable. The results may be used to describe historical trends to predict those in the future. In this study, the dependent variable was fish density, and was analyzed over time. The data points represented individual fish collected in the lock chamber surveys. A regression line was then fitted through the data points so that the squared deviations of the observed points were minimized. Confidence bands were placed around the regression line to define a 95% confidence limit. Therefore, there is a five- percent chance that the actual regression line for the population falls out of the limits defined by the bands. All species subjected to linear regression analyses were examined for river-wide abundance trends and trends in each of the three river sections.

Polynomial Regression Analysis

Standard or linear correlation was found to be inadequate in illustrating the density "spikes" of certain species; therefore, a custom regression line was applied to the data points. This new line—actually a smooth curve—allowed for discrimination of density peaks without influence of outliers or sporadic data points. It is also based upon maximum population densities and collection frequency. The following formula was derived to determine the line (curve) magnitude used in the regression equation:

$$M_L = \sqrt{N_{max}} \times \sqrt{10}$$

where, M_L = line or curve magnitude
N_{max} = largest number in collection

The subsequent regression equation was:

$$y = M_L * M_L * \text{normal}(x, Y_R, 5)$$

where, M_L = line or curve magnitude
Y_R = year of N_{max}
$5(\pm)$ = curve smoothness

All species subjected to polynomial regression analyses were examined for river-wide peaks in abundance along with those associated with a distinct river section.

Percent Family Composition

The species which demonstrated a positive temporal density correlation through linear regression analysis or were found to have undergone a significant peak in density by means of polynomial regression analysis were grouped at the family taxonomic level. Percentages of the family groups were then determined.

RESULTS

The 55 fish species meeting the criteria for examination were analyzed for overall temporal correlation in fish density and for significant density peaks. They were tested for trends throughout the entire river as well as in each of the three river sections. All were analyzed at the 95% confidence level and were considered significant at the level of $p \leq 0.05$.

Linear Regression Correlation Tests—Entire River

Twenty-eight species were selected for linear regression correlation analysis along the entire river. Of these, 23 species or 82% showed a significant positive correlation or overall increase in abundance over the 40-year period (Figs. 6-28). No species were found to have a significant negative correlation. Values for r, r^2, and p are found in Table 2.

Linear Regression Correlation Tests—Upper River

Twenty-three species were subjected to linear regression correlation analysis in the upper river section. Five species did not meet the established criteria for analysis. Fourteen species or 61% showed a significant positive correlation or abundance increase (Figs. 29-42). Only one species was found to have undergone a significant decrease in abundance (Fig. 43). Values for r, r^2, and p are found in Table 3.

Linear Regression Correlation Tests—Middle River

Twenty-two species were selected for linear regression correlation analysis in the middle river section. Seventeen species or 77% demonstrated a significant positive correlation or abundance increase (Figs. 44-60). Whereas, six species did not meet the criteria for analysis. One species demonstrated a significant negative correlation in abundance (Fig. 61). Values for r, r^2, and p are found in Table 4.

Linear Regression Correlation Tests—Lower River

Twenty species met the criteria for linear regression correlation analysis in the lower river section. Seven species or 35% showed a significant positive correlation or abundance increase (Figs. 62-68). No species demonstrated a significant negative correlation in abundance, and values for r, r^2, and p are found in Table 5.

Polynomial Regression Correlation Analysis—Entire River

Twenty-seven species or 49% of the original 55 species meeting the criteria for analysis demonstrated a significant peak in density through polynomial regression analysis (Figs. 69-95). No species were found to have undergone a significant decline in density. Values for r_L, r_L^2 and p_L are found in Table 6.

Polynomial Regression Correlation Analysis—Upper River

Nineteen species met the criteria for polynomial regression analysis in the upper river section. Twelve species or 63% showed a significant peak in density (Figs.96-108). All peaks were experienced between 1957 and 1970, and no species were found to demonstrate a significant decline in density. Values for r_L, r_L^2, and p_L are found in Table 7.

Polynomial Regression Correlation Analysis—Middle River

Nineteen species were subjected to polynomial regression analysis in the middle river section. Eleven species or 58% demonstrated a significant peak in density, and all peaks were between 1968 and 1980 (Figs. 109-119). No species were found to show a significant decline in density. Values for r_L, r_L^2, and p_L are found in Table 8.

Polynomial Regression Correlation Analysis—Lower River

Eleven species were selected for polynomial regression analysis in the lower river section. Eight species or 72% showed a significant peak in density, and all but 1 peak were found between 1976 and 1997 (Figs. 120-127). No species were found to show a significant decline in density. Values for r_L, r_L^2, and p_L are found in Table 9.

Percent Family Composition

Percent composition of species, grouped into taxonomic families, that showed either a positive temporal density correlation through linear regression analysis or demonstrated a density peak by means of polynomial regression analysis are illustrated in Figures 128-135.

DISCUSSION

Fifty-five species of Ohio River fishes were analyzed through linear regression correlation for temporal density trends or through polynomial regression for peak density trends. Analyses showed many species demonstrated a positive temporal density correlation in one or all of the river sections. These species are possibly responding to the water quality improvements that occurred during the 40-year study period, particularly improvements that were a result of the Clean Water Act of 1972. Other species, which show a density peak through polynomial regression analysis, are likely responding to the construction of high-lift dams along the reach of the Ohio River. These peaks, which may occur in one or all of the river sections, closely parallel the time periods in which a series of high-lift dams were placed into operation. Fish populations exhibiting such a sharp increase in abundance are, in all probability, reacting to additional resources introduced into the channel by dam-expanded waters.

Linear Regression Correlation Analysis—Entire River

This analysis was designed to reveal all populations of Ohio River fishes that demonstrate a significant temporal density correlation, either positive or negative. It was found that 23 species exhibited a positive correlation at $p \leq 0.05$ (Figs. 6-28), and no species demonstrated a negative correlation (Table 2). From these results, it was realized that all of the species meeting the criteria for analysis throughout the entire river showed either a positive correlation for a density increase or no temporal density trend. These findings are supported by the fact that there has been a continual improvement in water quality since data collection began in 1957, and there has been a gradual growth in pollution intolerant species (Pearson and Pearson, 1989). The largest groups showing these density increases were the suckers (family Catostomidae) and the sunfishes (family Centrarchidae)(Fig. 128).

Linear Regression Correlation Analysis—Upper River

In the upper river section, fourteen species demonstrated a positive temporal density correlation at $p \leq 0.05$ (Figs. 29-42), and one species was found to have a negative density correlation (Fig. 43)(Table 3). Percentage-wise, fishes having a positive correlation represent a small portion of those analyzed; however, extraneous factors contributing to this do exist. Being the most industrialized section of the river, the upper Ohio has been the recipient of much pollution. Many of these pollutants included heavy metals that can remain as part of the sediment for a number of years (Cavanaugh and Mitsch, 1989). Therefore, an improvement in water quality through the control of waters discharged into the river may be offset by the residual effect of toxins in the sediment. The impact of such toxins to fishes may be either lethal or sub-lethal (Welcomme, 1985). Groups that showed the largest density increases were the suckers (family Catostomidae) and the sunfishes (family Centrarchidae)(Fig. 129).

Linear Regression Correlation Analysis—Middle River

Seventeen species demonstrated a positive temporal density correlation in the middle river section at $p \leq 0.05$ (Figs. 44-60). Yet, one species was found to exhibit a negative correlation (Fig. 61)(Table 4). In terms of percentage of fish analyzed, the middle river section had the largest proportion of species showing a positive growth trend. These results were expected since the middle river section was the largest in length and was not directly subjected to the industrial pollutants that were discharged into the upper river. The middle river section had the largest number of taxa in the linear regression analyses with nine families represented: sunfishes (family Centrarchidae), herrings (family Clupeidae), and suckers (family Catostomidae) were most abundant (Fig. 130). These findings were supported by other studies that found the middle river section to be the most productive in terms of density and diversity (Pearson and Person, 1989).

Linear Regression Correlation Analysis—Lower River

Seven species were found to have a positive temporal density correlation through linear regression analysis at $p \leq 0.05$ (Figs. 62-68). However, no species analyzed exhibited a negative correlation (Table 5). The lower river section had the lowest percentage of species showing a positive density correlation in regard to water quality improvements; yet, some sampling biases may contribute to these findings. The upper and middle river sections of the river have received much more attention, in terms of collections, than the lower river. If an equal amount of collecting effort were given to the lower river, it may reveal even more species than the other two section—since it could draw species from the Mississippi River (Pearson and Person, 1989). Only four families were represented by fishes showing a positive density correlation, with herrings (family Clupeidae) being the most abundant (Fig. 131).

Polynomial Regression Analysis—Entire River

This analysis was designed to reveal all populations of Ohio River fishes that demonstrate a significant peak or decline in density at $p \leq 0.05$. Through polynomial regression analysis, 27 species were found to have undergone such a density "spike" during the 40-year period of data collection (Figs. 69-95). Yet, no species were found to have undergone a significant decline (Table 6). Density peaks ranged in years from 1957 to 1997, implying that several incremental changes influenced populations rather than a few, more dramatic alterations. Nine families of fishes exhibited the density peak (Fig. 132) with the sunfishes (family Centrarchidae) and minnows (family Cyprinidae) dominating the group. The abundance of these taxa was predicted, especially in the case of the Centrarchids, since they are known to prefer habitats rich in vegetation and cover substrate. These resources were probably depleted as a submerged and overhanging component to the water prior to the construction of the high-lift dams. However, as the new dams were placed into operation along the reach of the river, the elevated water level produced embayments and backwater pools filled with submerged and overhanging vegetation as well as new channel substrates. In all likelihood, the resident fish populations presented with these plentiful yet necessary resources experienced unrestricted growth. In addition, the results of species density taken from the individual river sections support the theory that many fish species have responded similarly to the high-lift dams, and the lock chamber surveys have provided an accurate "snapshot" of these density changes.

Polynomial Regression Analysis—Upper River

Polynomial regression analysis of species collected from the upper river reveals that 12 species demonstrated a density peak in that section at $p \leq 0.05$ (Figs. 96-108). All significant peaks were between 1957 and 1970. This period of time corresponds closely with the span in which the high-lift dams in this river section were placed into operation—much earlier than the dams in the other river sections. Although the response of some populations to the new habitat seems delayed, it is not uncommon for certain species to experience a "reaction lag." These species often require more time for habitat acclimation or simply cannot allocate resources as quickly as others. Again, minnows (family Cyprinidae) and sunfishes (family Centrarchidae) dominated this group of fishes (Fig. 133).

Polynomial Regression Analysis—Middle River

Eleven species examined by means of polynomial regression analysis showed a significant peak in density in the middle river section at $p \leq 0.05$ (Figs. 109-119). No species were found to have undergone a significant decline in density in the middle river section (Table 8). All significant peaks occurred between the years of 1968 and 1980. This interval is during and shortly after the period in which many high-lift dams became operational in this river section. In general, high-lift dams along the middle river were built in series after those constructed along the upper section. Subsequently, the sharp increases in fish density mirror this pattern. The two taxonomic groups found to be most successful in acquiring the newly introduced resources, the sunfishes (family Centrarchidae) and the minnows (family Cyprinidae), dominated the assemblage (Fig. 134).

Polynomial Regression Analysis—Lower River

Polynomial regression analysis of species collected from the lower river section reveals that eight species have undergone a significant peak in density at $p \leq 0.05$ (Figs. 120-127). No species experienced a rapid decline in abundance (Table 9), and all but two density peaks were between the years of 1976 and 1997. Since the dams along the lower river were among the last to be constructed, these density increases are probably a product of the favorable habitat conditions created by the dams. Lending further support are the two groups found to reflect the largest changes in density, the sunfishes (family Centrarchidae) and the minnows (family Cyprinidae)(Fig. 135). In regard to the species demonstrating density peaks prior to the aforementioned time period, they may have increased in abundance as a downstream effect of dam construction in the upper and middle river sections or as a result of earlier dam construction in the lower river.

CONCLUSIONS

① The Ohio River has changed dramatically over the past 200 years. These changes were the result of water quality degradation and alterations to the natural flow of water through the channel.

② Fish populations in the Ohio River have shifted in composition and abundance in response to the environmental conditions created by pollution and initial dam construction.

③ Many fish populations have undergone gradual increases in density which correspond with water quality improvements initiated by the Clean Water Act, 1972.

④ Other fish populations have demonstrated a peak in density which mirrors periods of high-lift dam construction. These species are likely responding to favorable habitat conditions created by elevated water levels.

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APPENDIX

River Section	Beginning River Mile	Ending River Mile	Number of Sampling Events
Entire River	0.0	981.0	341
Upper River	0.0	202.6	94
Middle River	203.0	705.0	170
Lower River	710.0	981.0	77

Table 1. Defined river sections and number of sampling events per section.

Species Name	p =	r =	r^2 =	Species Name	p =	r =	r^2 =
Bigmouth Buffalo	0.748497	0.017425	0.000304	Mooneye	0.000004	0.246356	0.060689
Blue Catfish	0.052449	0.103071	0.010624	Quillback Carpsucker	0.000000	0.270182	0.072949
Bluegill	0.000000	0.313726	0.098424	River Carpsucker	0.004777	0.152470	0.023247
Carp	0.000001	0.262828	0.069079	Rock Bass	0.000064	0.213767	0.045696
Channel Catfish	0.036416	0.113353	0.012849	Sauger	0.000000	0.289768	0.083965
Flathead Catfish	0.000001	0.260718	0.067974	Shorthead Redhorse	0.000015	0.232036	0.053841
Freshwater Drum	0.000003	0.248653	0.061828	Shortnose Gar	0.329434	0.052970	0.002806
Gizzard Shad	0.000000	0.278389	0.077500	Skipjack Herring	0.000000	0.284754	0.081085
Golden Redhorse	0.175905	0.073465	0.005397	Smallmouth Bass	0.000010	0.236561	0.055961
Green Sunfish	0.084135	-0.093670	0.008774	Smallmouth Buffalo	0.000000	0.390552	0.152530
Largemouth Bass	0.013072	0.134281	0.018031	Spotted Sucker	0.000854	0.179762	0.032314
Logperch	0.000422	0.189905	0.036064	Threadfin Shad	0.006615	0.146801	0.021551
Longear Sunfish	0.002278	0.123293	0.015201	Walleye	0.000000	0.408555	0.166917
Longnose Gar	0.004838	0.152251	0.023180	Yellow Bass	0.009813	0.139668	0.019507

Table 2. Values from linear regression analyses of species examined along the entire river.

Species Name	p =	r =	r^2 =	Species Name	p =	r =	r^2 =
Bigmouth Buffalo	insufficient data			Mooneye	0.002906	0.303874	0.092340
Blue Catfish	insufficient data			Quillback Carpsucker	0.001041	0.332980	0.110876
Bluegill	0.005755	0.282764	0.079955	River Carpsucker	0.136722	0.154631	0.023911
Carp	0.250979	0.119579	0.014299	Rock Bass	0.015133	0.249905	0.062453
Channel Catfish	0.838439	0.021313	0.000454	Sauger	0.001894	0.316364	0.100086
Flathead Catfish	0.000001	0.481757	0.232090	Shorthead Redhorse	0.000371	0.359621	0.129328
Freshwater Drum	0.000000	0.520394	0.270810	Shortnose Gar	insufficient data		
Gizzard Shad	0.031375	0.222181	0.049365	Skipjack Herring	0.000802	0.339951	0.115567
Golden Redhorse	0.713767	-0.038332	0.001469	Smallmouth Bass	0.005449	0.284511	0.080946
Green Sunfish	0.008380	-0.270451	0.073144	Smallmouth Buffalo	0.000792	0.340249	0.115769
Largemouth Bass	0.565718	-0.059991	0.003599	Spotted Sucker	0.045436	0.206876	0.042789
Logperch	0.091228	0.175196	0.030694	Threadfin Shad	insufficient data		
Longear Sunfish	0.237920	-0.122911	0.015107	Walleye	0.000040	0.456138	0.208062
Longnose Gar	0.122651	0.160338	0.025708	Yellow Bass	insufficient data		

Table 3. Values from linear regression analyses of species examined along the upper river section.

Species Name	p =	r =	r^2 =	Species Name	p =	r =	r^2 =
Bigmouth Buffalo	0.111367	0.122550	0.015019	Mooneye	0.000485	0.264740	0.070087
Blue Catfish	0.034219	-0.162521	0.026413	Quillback Carpsucker	0.000000	0.414850	0.172101
Bluegill	0.000000	0.376746	0.141937	River Carpsucker	0.013093	0.190070	0.036127
Carp	0.000000	0.423603	0.179439	Rock Bass	insufficient data		
Channel Catfish	0.442096	-0.059339	0.003521	Sauger	0.000001	0.362201	0.131190
Flathead Catfish	0.000000	0.389876	0.152004	Shorthead Redhorse	insufficient data		
Freshwater Drum	0.000000	0.453836	0.205967	Shortnose Gar	insufficient data		
Gizzard Shad	0.000034	0.312080	0.097394	Skipjack Herring	0.000002	0.354727	0.125831
Golden Redhorse	insufficient data			Smallmouth Bass	0.000096	0.294742	0.086873
Green Sunfish	0.221966	-0.094157	0.008866	Smallmouth Buffalo	0.000000	0.457958	0.209726
Largemouth Bass	0.005245	0.213210	0.045459	Spotted Sucker	0.000896	0.252456	0.063734
Logperch	insufficient data			Threadfin Shad	0.530599	-0.048425	0.002345
Longear Sunfish	0.002382	0.231535	0.053608	Walleye	0.000000	0.407901	0.166383
Longnose Gar	0.000837	0.253845	0.064437	Yellow Bass	insufficient data		

Table 4. Values from linear regression analyses of species examined along the middle river section.

Species Name	p =	r =	r^2 =	Species Name	p =	r =	r^2 =
Bigmouth Buffalo	0.651800	-0.052246	0.002730	Mooneye	0.004340	0.321628	0.103445
Blue Catfish	0.031520	0.245320	0.060128	Quillback Carpsucker	0.071202	0.206760	0.042750
Bluegill	0.103294	0.187066	0.034994	River Carpsucker	0.155746	0.163353	0.026684
Carp	0.060204	0.215169	0.046298	Rock Bass	insufficient data		
Channel Catfish	0.000017	0.468367	0.219367	Sauger	0.397647	0.097754	0.009556
Flathead Catfish	0.839479	0.023465	0.000551	Shorthead Redhorse	insufficient data		
Freshwater Drum	0.093254	0.192635	0.037108	Shortnose Gar	0.331990	0.112039	0.012553
Gizzard Shad	0.005890	0.311087	0.096775	Skipjack Herring	0.001343	0.359039	0.128909
Golden Redhorse	insufficient data			Smallmouth Bass	0.364212	0.100557	0.010112
Green Sunfish	0.763602	-0.034833	0.001213	Smallmouth Buffalo	insufficient data		
Largemouth Bass	insufficient data			Spotted Sucker	insufficient data		
Logperch	insufficient data			Threadfin Shad	0.004804	0.318162	0.101227
Longear Sunfish	0.121160	0.178128	0.031729	Walleye	0.022541	0.259728	0.067459
Longnose Gar	0.776568	-0.032870	0.001080	Yellow Bass	insufficient data		

Table 5. Values from linear regression analyses of species examined along the lower river section.

Species Name	p =	r =	r^2 =	Species Name	p =	r =	r^2 =
American Eel	0.866511	0.009136	0.000083	Redear Sunfish	0.316055	-0.054453	0.002965
Black Bullhead	0.025803	-0.120717	0.014573	River Shiner	0.001408	-0.172248	0.029669
Black Crappie	0.736330	-0.018300	0.000335	Sand Shiner	0.394438	-0.046262	0.002140
Bluntnose Minnow	0.548631	-0.029784	0.000887	Silver Chub	0.013582	-0.133545	0.017835
Brown Bullhead	0.327164	-0.053219	0.002832	Spotfin Shiner	0.390494	-0.046648	0.002176
Emerald Shiner	0.062316	-0.101056	0.010212	Spotted Bass	0.009907	0.134992	0.019458
Ghost Shiner	0.956872	0.002326	0.000005	Striped Bass	0.097931	0.089770	0.008059
Goldeye	0.357623	-0.049968	0.002497	Warmouth	0.708691	-0.020309	0.000412
Highfin Carpsucker	0.011536	0.136652	0.018674	White Bass	0.000090	0.238406	0.056837
Hybrid Striper	0.005274	0.150764	0.022730	White Catfish	0.818598	0.012465	0.000155
Mimic Shiner	0.438178	-0.042119	0.001774	White Crappie	0.104936	0.087955	0.007736
Orangespotted Sunfish	0.774182	-0.085930	0.000243	Yellow Bullhead	0.781739	-0.015058	0.000227
Paddlefish	0.137880	0.080514	0.006482	Yellow Perch	0.379362	0.048255	0.002329
Pumpkinseed	0.869494	-0.008930	0.000080				

Table 6. Values from polynomial regression analyses of species examined along the entire river.

Species Name	p =	r =	r^2 =	Species Name	p =	r =	r^2 =
American Eel	insufficient data			Redear Sunfish	insufficient data		
Black Bullhead	0.000500	-0.352168	0.124022	River Shiner	0.020297	-0.239090	0.057164
Black Crappie	0.099942	-0.170719	0.029145	Sand Shiner	0.002029	-0.314381	0.098835
Bluntnose Minnow	0.085154	-0.178522	0.031870	Silver Chub	0.000552	-0.349612	0.122228
Brown Bullhead	0.015112	-0.249956	0.062478	Spotfin Shiner	0.027705	-0.227124	0.051585
Emerald Shiner	0.006868	-0.277040	0.076751	Spotted Bass	0.945940	-0.007088	0.000050
Ghost Shiner	0.870805	-0.017001	0.000289	Striped Bass	0.284258	0.111593	0.012453
Goldeye	insufficient data			Warmouth	insufficient data		
Highfin Carpsucker	insufficient data			White Bass	0.039041	0.213258	0.045479
Hybrid Striper	0.115616	0.163382	0.026694	White Catfish	0.439298	-0.080718	0.006515
Mimic Shiner	0.015591	-0.248827	0.061915	White Crappie	0.730066	0.036059	0.001300
Orangespotted Sunfish	insufficient data			Yellow Bullhead	0.032956	-0.220202	0.048489
Paddlefish	insufficient data			Yellow Perch	0.725393	-0.036709	0.001348
Pumpkinseed	insufficient data						

Table 7. Values from polynomial regression analyses of species examined along the upper river section.

Species Name	p =	r =	r^2 =	Species Name	p =	r =	r^2 =
American Eel	0.857011	0.013921	0.000194	Redear Sunfish	insufficient data		
Black Bullhead	0.749815	-0.024635	0.000607	River Shiner	0.033514	-0.163156	0.026620
Black Crappie	0.447877	0.058592	0.003433	Sand Shiner	0.822405	-0.017341	0.000301
Bluntnose Minnow	0.597424	-0.040788	0.001664	Silver Chub	0.068658	-0.139983	0.019595
Brown Bullhead	0.934461	-0.006354	0.000040	Spotfin Shiner	insufficient data		
Emerald Shiner	0.124044	-0.118419	0.014023	Spotted Bass	0.001790	0.237833	0.056565
Ghost Shiner	0.921990	0.007566	0.000057	Striped Bass	0.103031	0.125472	0.015743
Goldeye	0.347281	-0.072525	0.005260	Warmouth	insufficient data		
Highfin Carpsucker	insufficient data			White Bass	0.000032	0.313039	0.097994
Hybrid Striper	0.000099	0.294093	0.086491	White Catfish	insufficient data		
Mimic Shiner	0.670899	0.032823	0.001077	White Crappie	0.007990	0.202816	0.041134
Orangespotted Sunfish	0.525494	-0.049027	0.002404	Yellow Bullhead	insufficient data		
Paddlefish	0.048204	0.151760	0.023031	Yellow Perch	insufficient data		
Pumpkinseed	insufficient data						

Table 8. Values from polynomial regression analyses of species examined along the middle river section.

Species Name	p =	r =	r^2 =	Species Name	p =	r =	r^2 =
American Eel	0.230478	0.138257	0.019155	Redear Sunfish	insufficient data		
Black Bullhead	insufficient data			River Shiner	insufficient data		
Black Crappie	0.575449	-0.064816	0.004201	Sand Shiner	insufficient data		
Bluntnose Minnow	insufficient data			Silver Chub	0.865059	-0.019598	0.000384
Brown Bullhead	insufficient data			Spotfin Shiner	insufficient data		
Emerald Shiner	0.218200	0.141933	0.020145	Spotted Bass	insufficient data		
Ghost Shiner	insufficient data			Striped Bass	0.102065	0.187727	0.035241
Goldeye	0.262797	0.129191	0.016690	Warmouth	0.705576	-0.043750	0.001914
Highfin Carpsucker	insufficient data			White Bass	0.000000	0.564351	0.318492
Hybrid Striper	insufficient data			White Catfish	insufficient data		
Mimic Shiner	0.144851	0.167714	0.028128	White Crappie	0.790487	0.030773	0.000947
Orangespotted Sunfish	insufficient data			Yellow Bullhead	insufficient data		
Paddlefish	0.443264	0.088651	0.007859	Yellow Perch	insufficient data		
Pumpkinseed	insufficient data						

Table 9. Values from polynomial regression analyses of species examined along the lower river section.

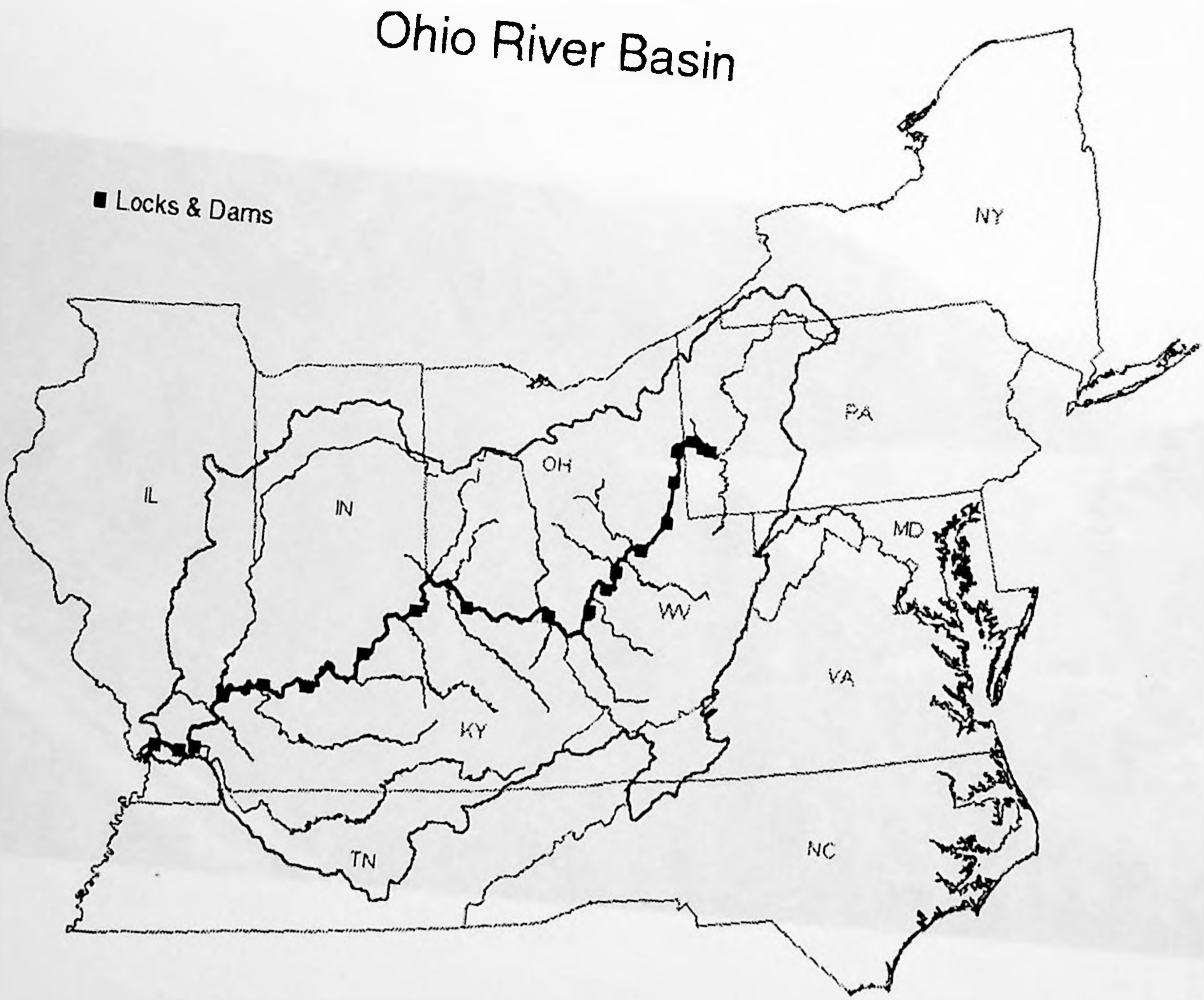

Fig. 1. Ohio River Drainage Basin.

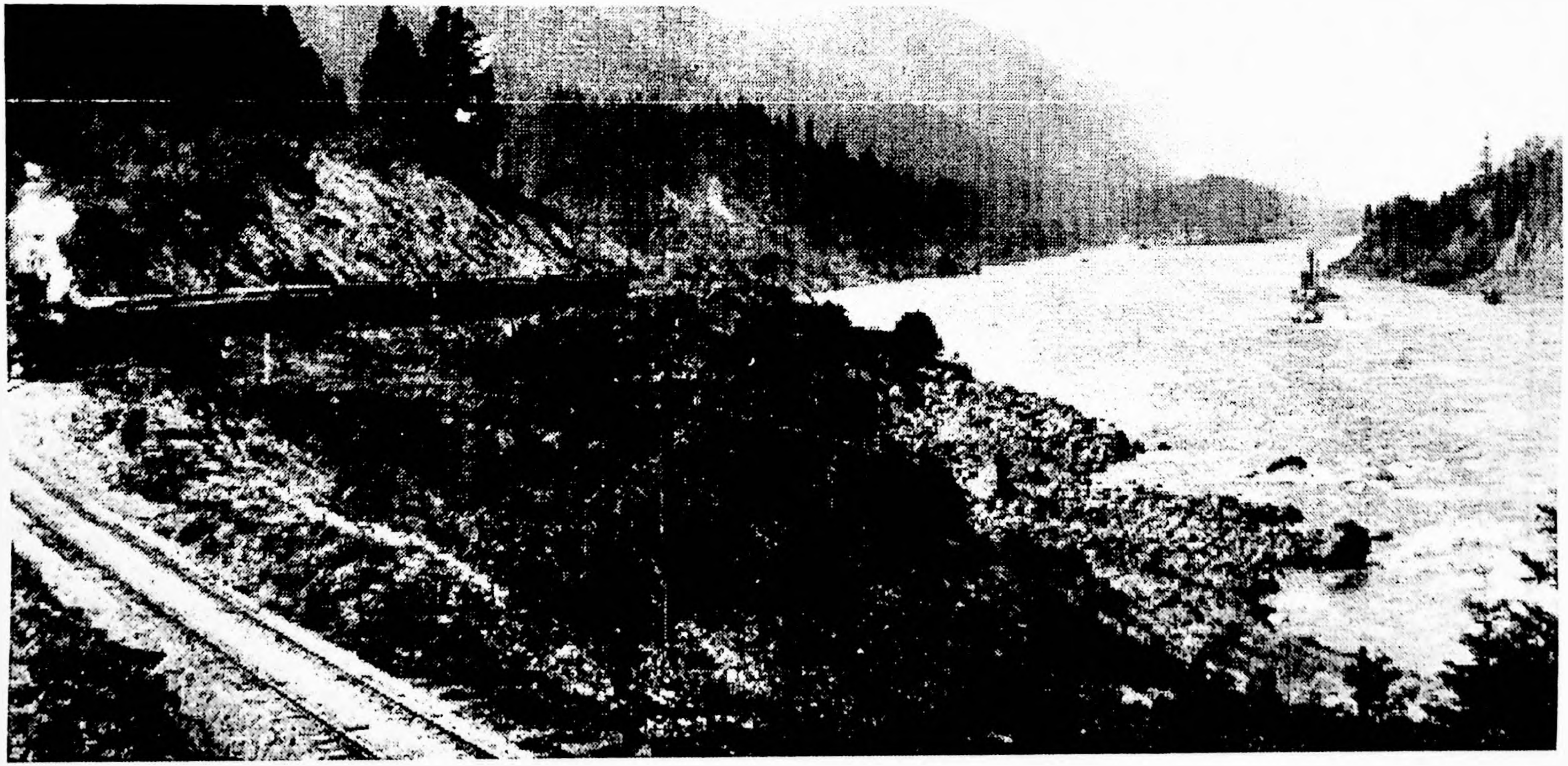

Fig. 2. Historic photograph of navigation along the Ohio River.

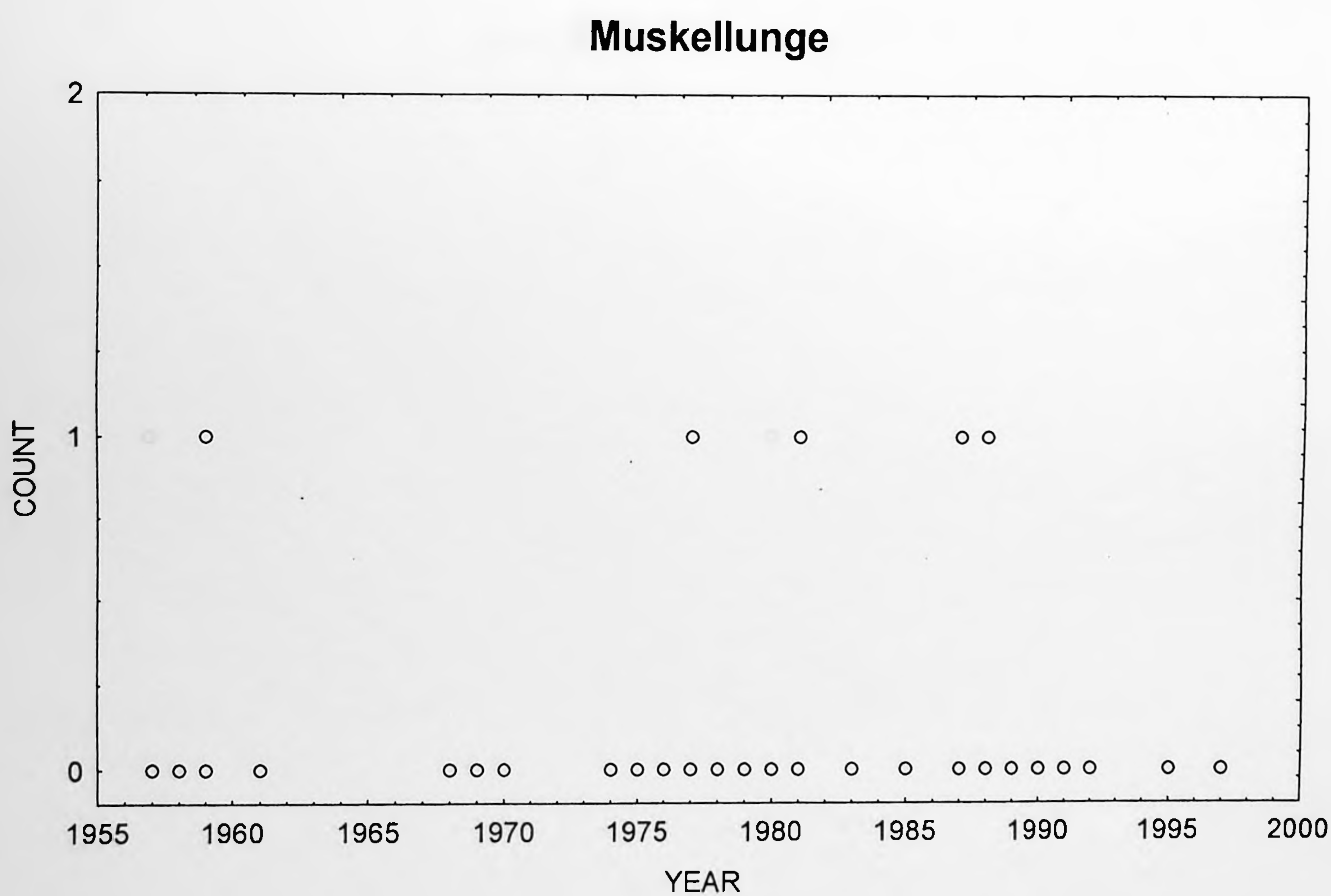

Fig. 3. Example scatterplot of species excluded on the basis of sample size.

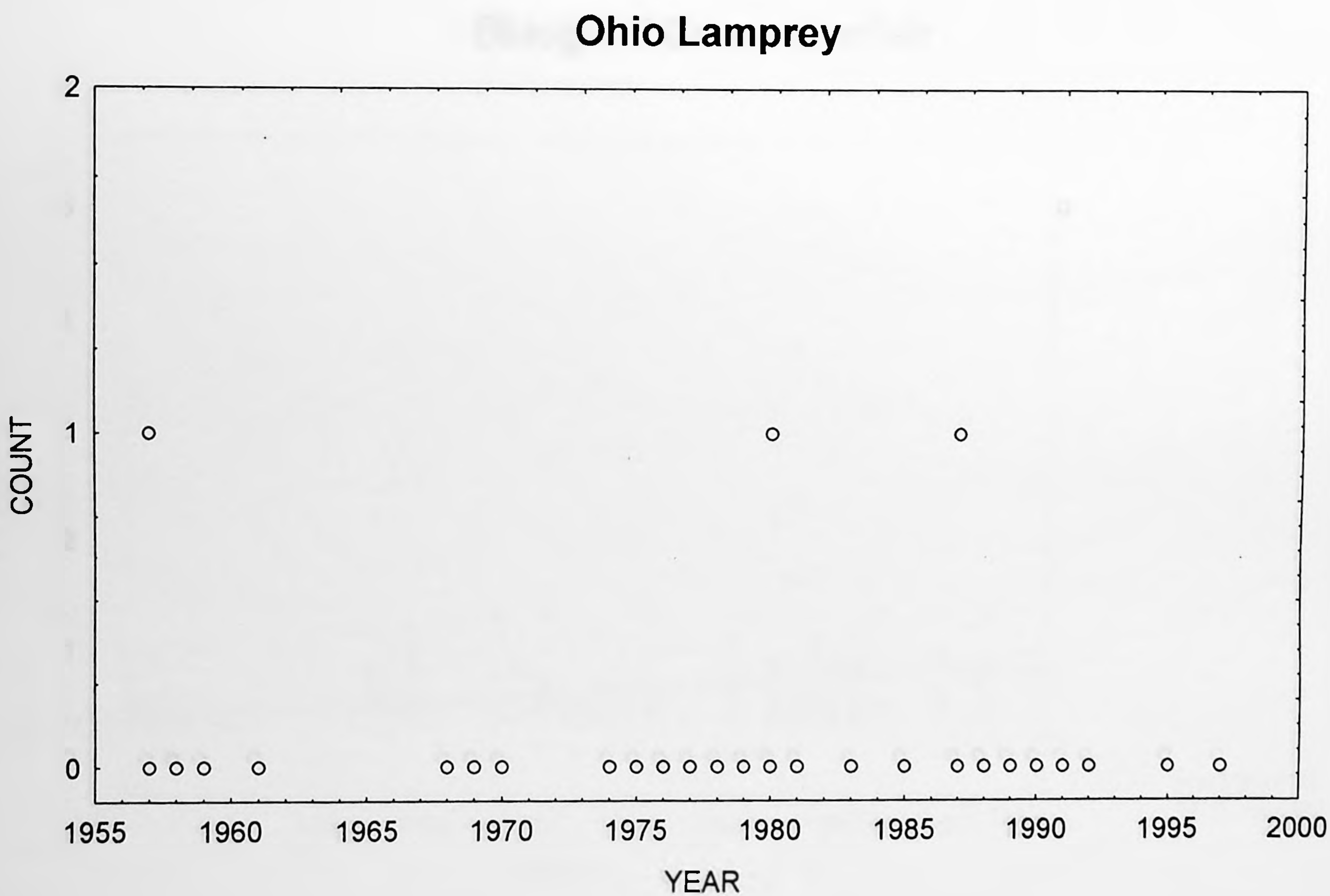

Fig. 4. Example scatterplot of species excluded on the basis of sporadic collection.

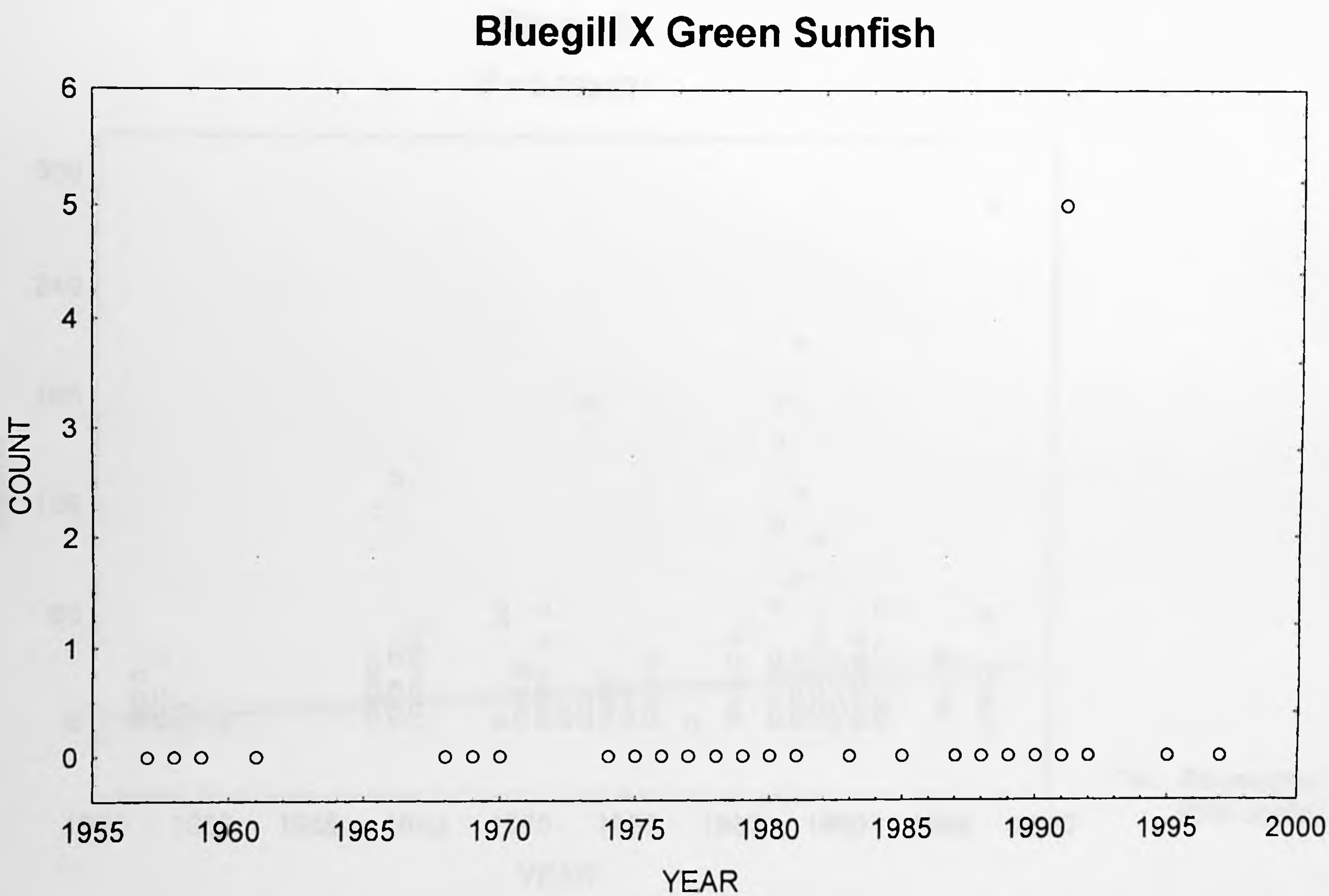

Fig. 5. Example scatterplot of hybrid species excluded.

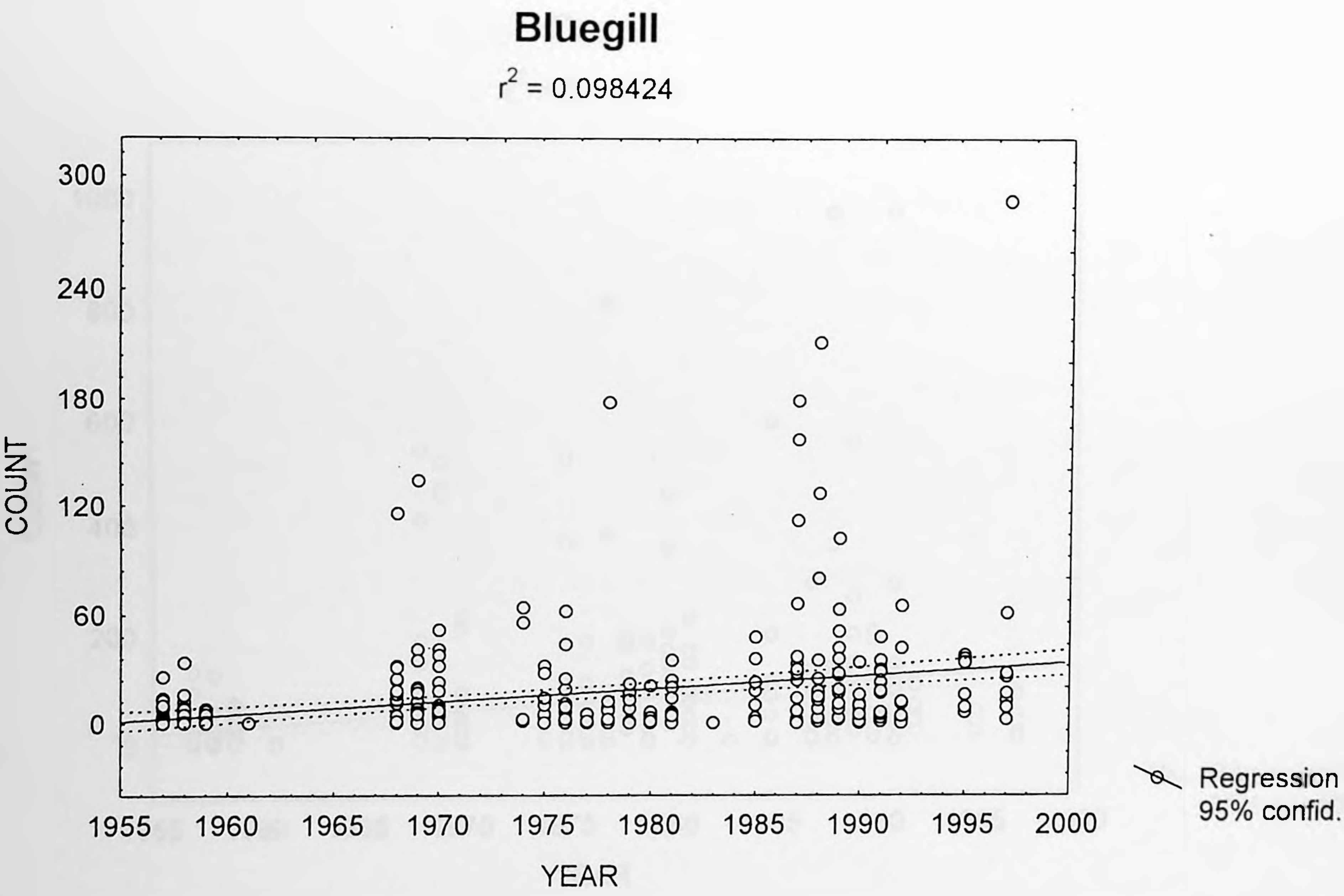

Fig. 6. Species showing a positive temporal/density correlation along the entire river.

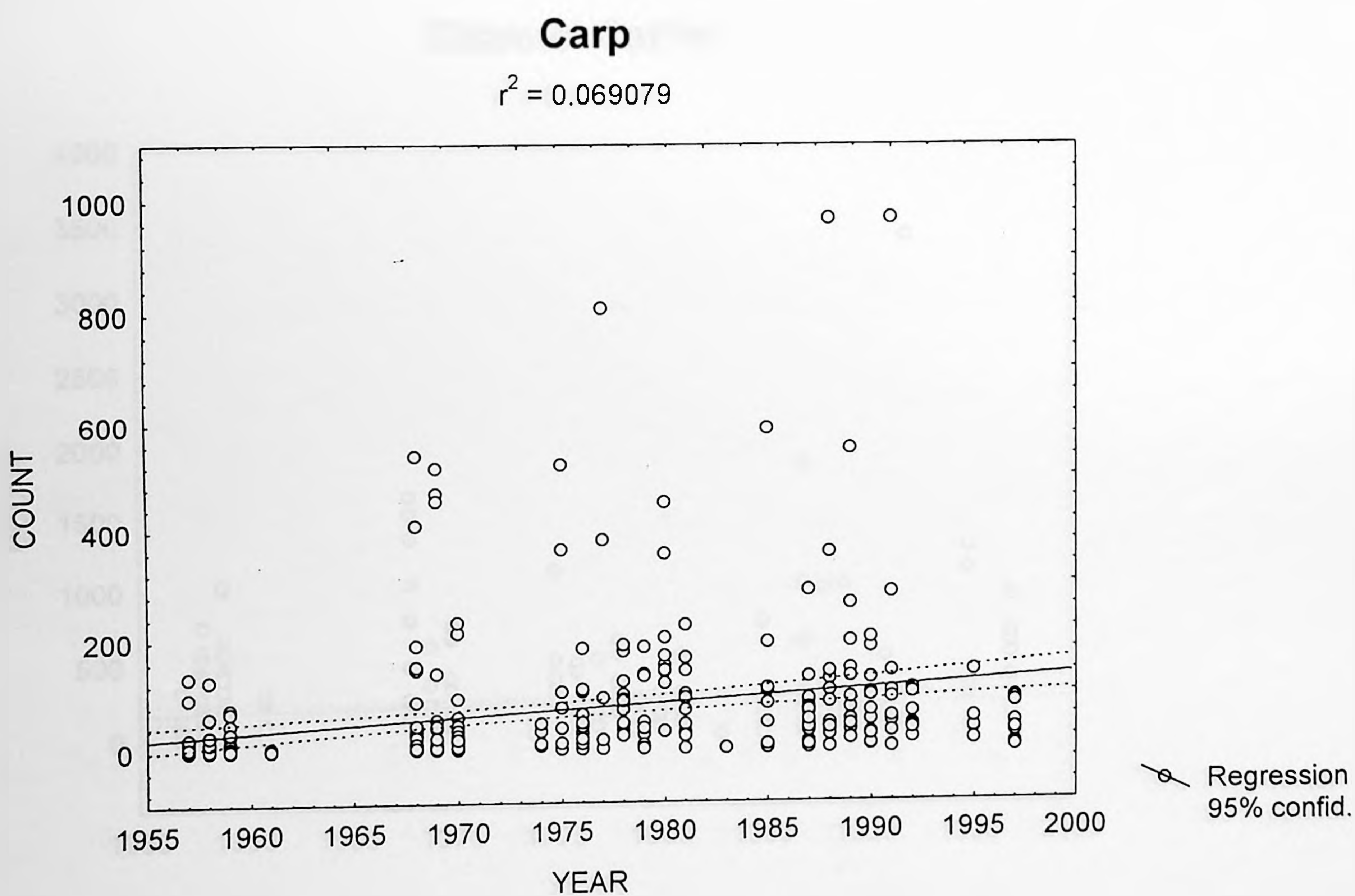

Fig. 7. Species showing a positive temporal/density correlation along the entire river.

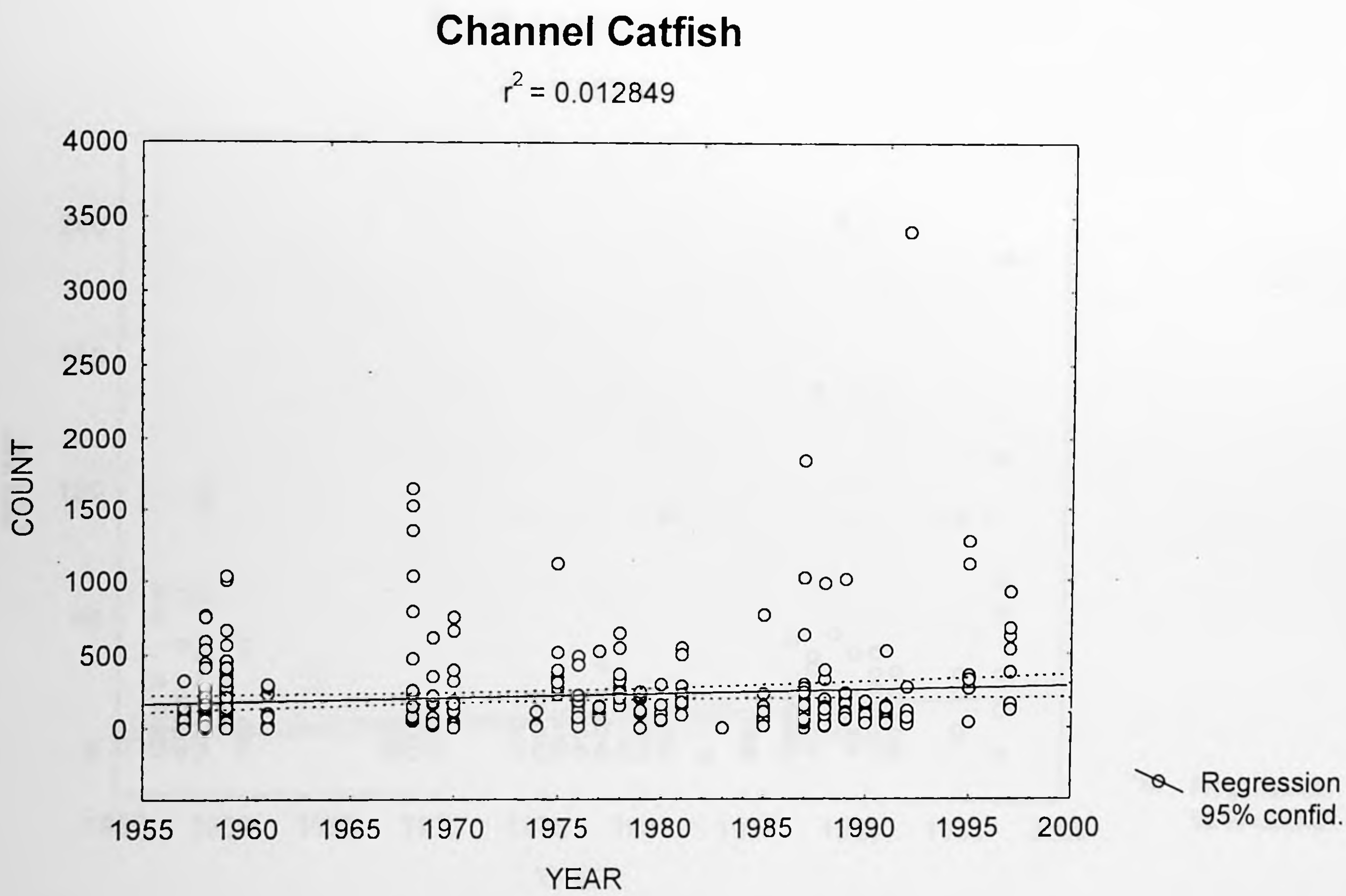

Fig. 8. Species showing a positive temporal/density correlation along the entire river.

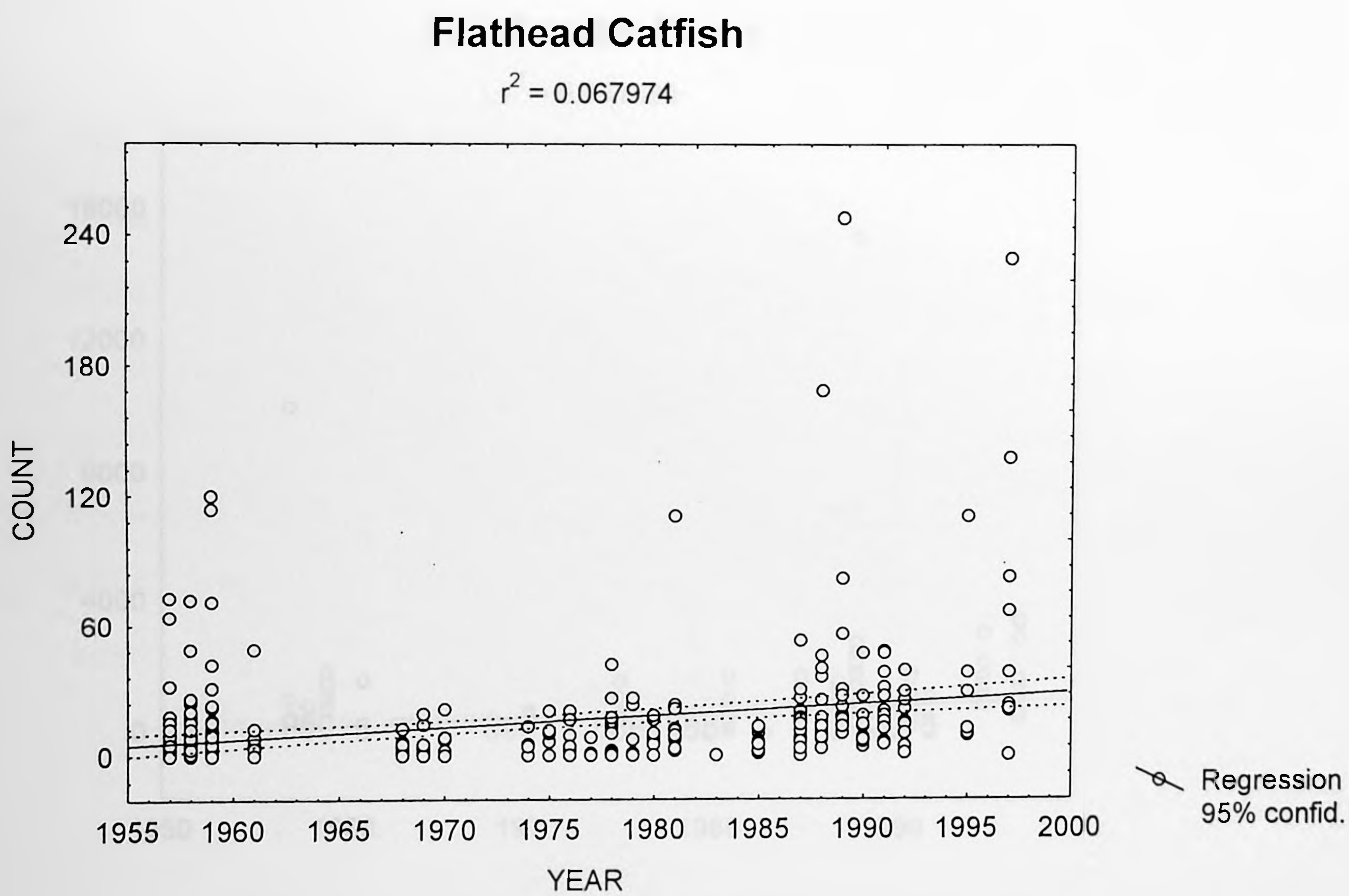

Fig. 9. Species showing a positive temporal/density correlation along the entire river.

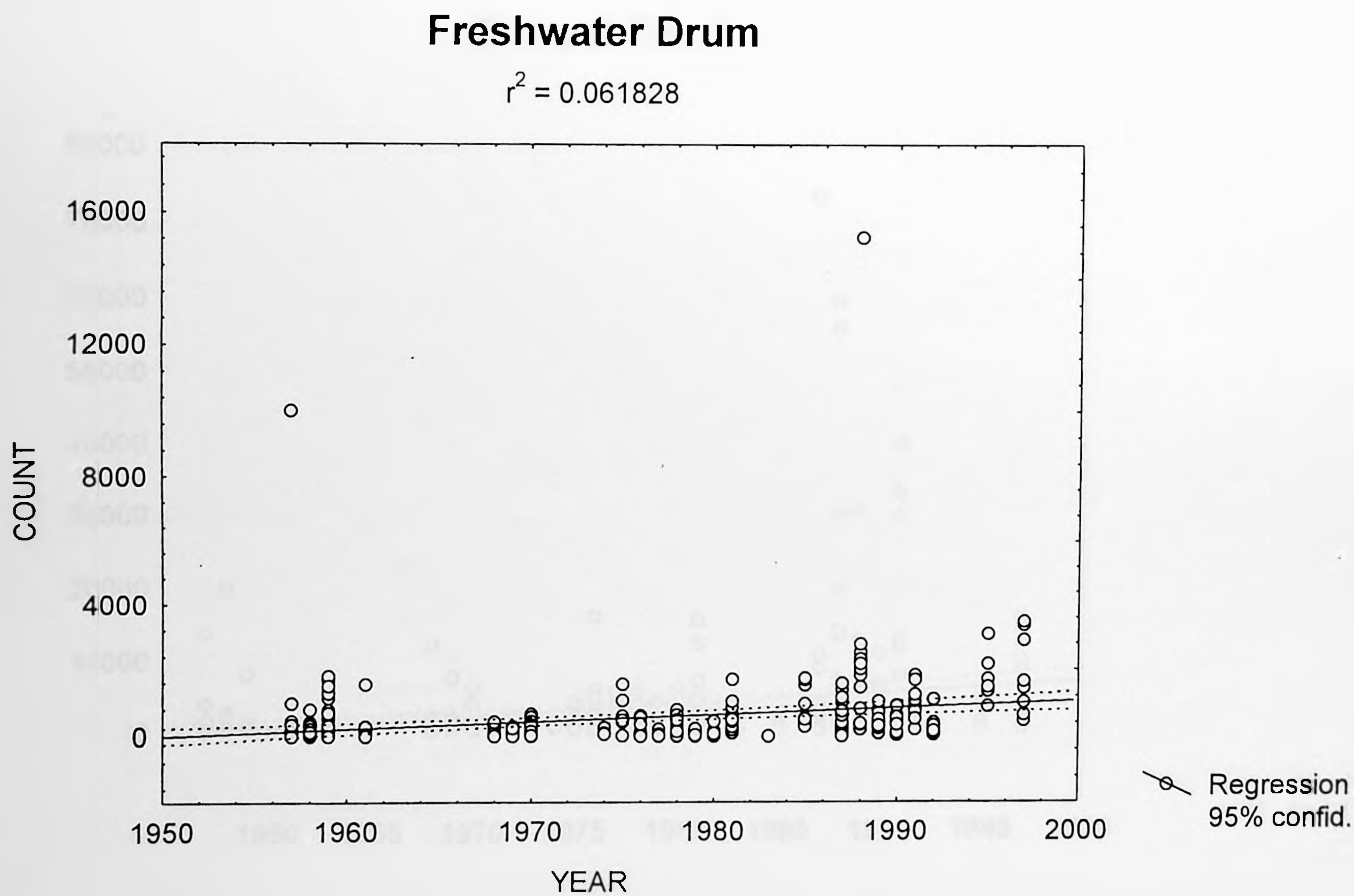

Fig. 10. Species showing a positive temporal/density correlation along the entire river.

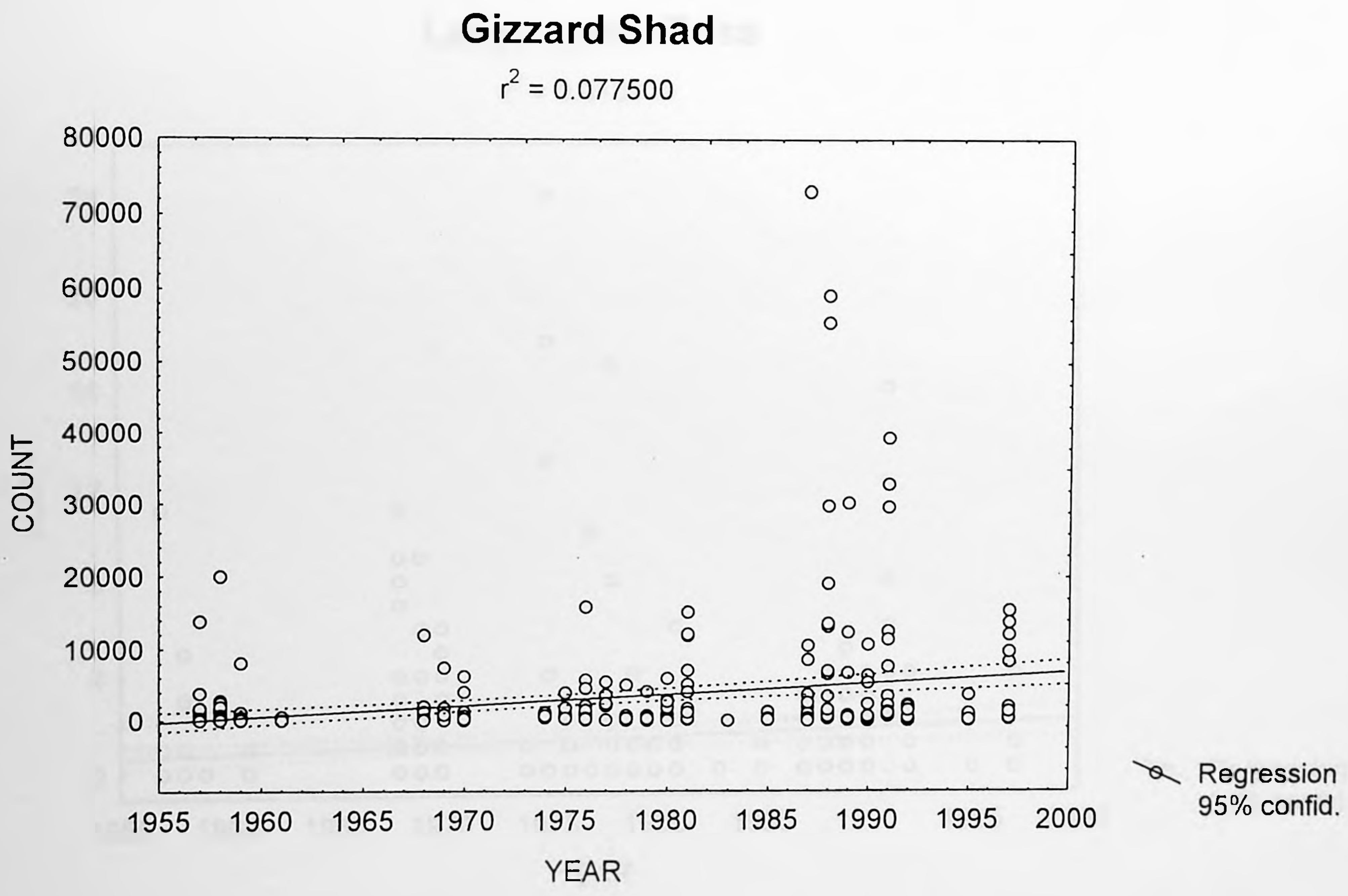

Fig. 11. Species showing a positive temporal/density correlation along the entire river.

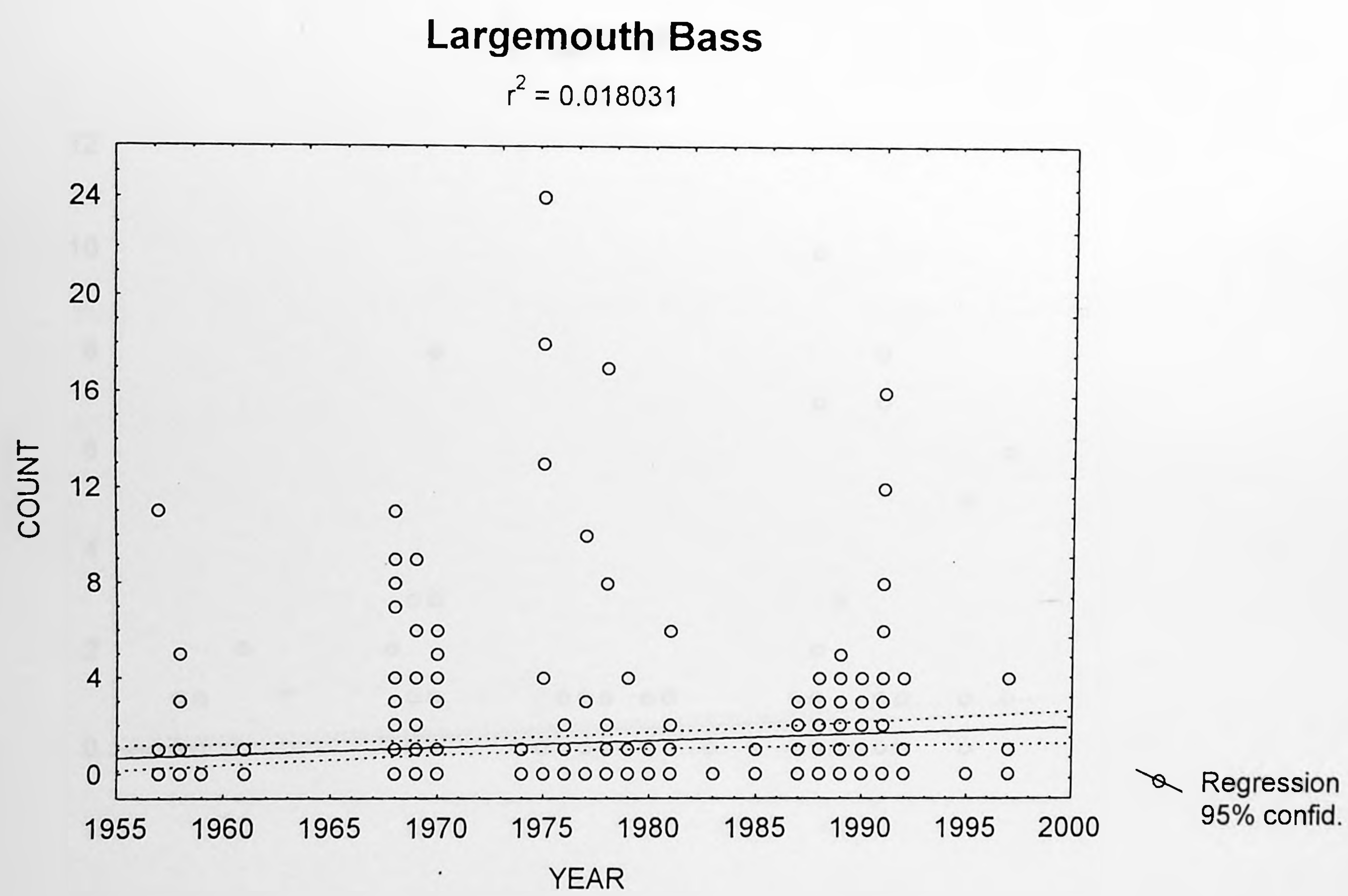

Fig. 12. Species showing a positive temporal/density correlation along the entire river.

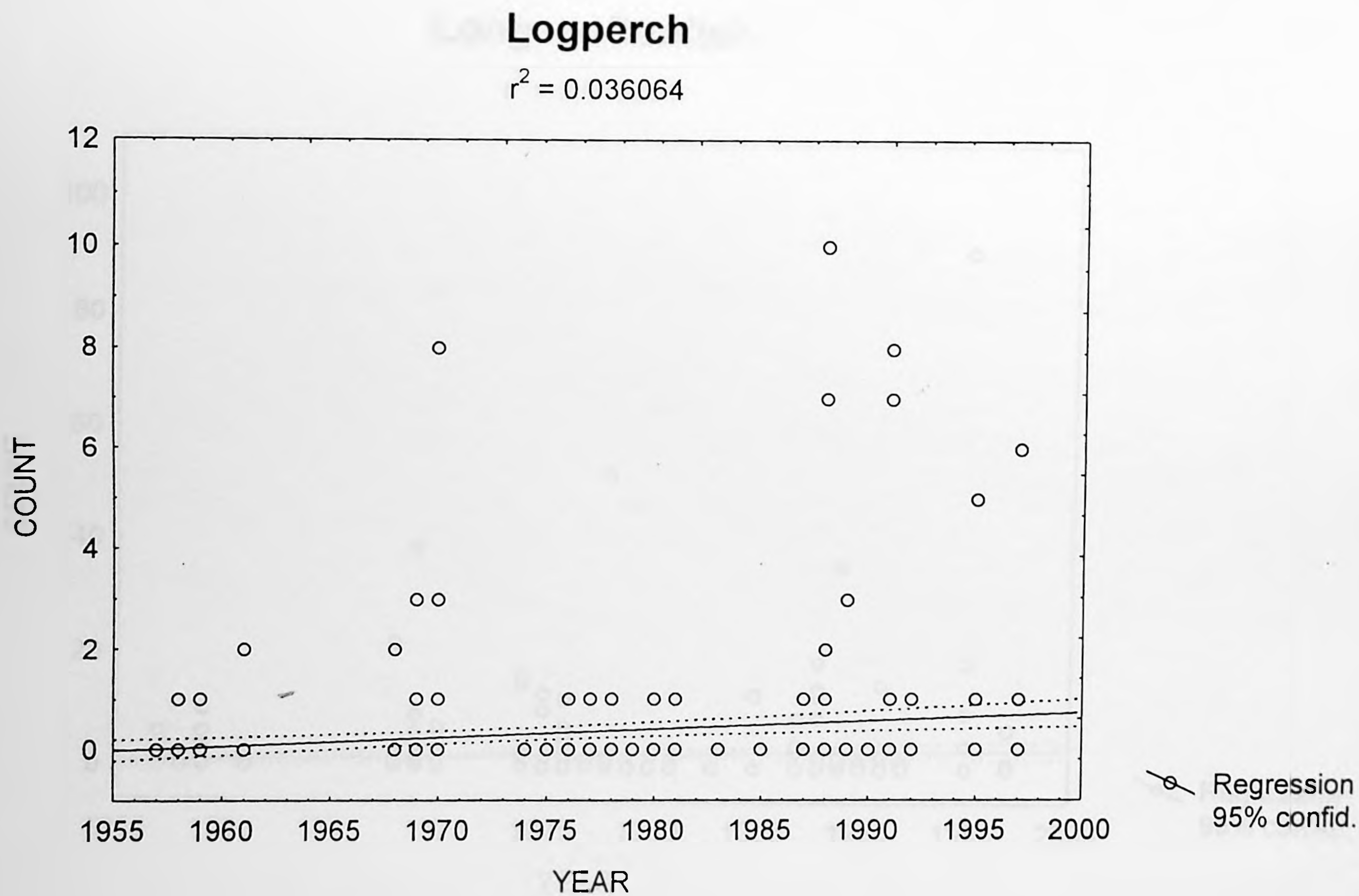

Fig. 13. Species showing a positive temporal/density correlation along the entire river.

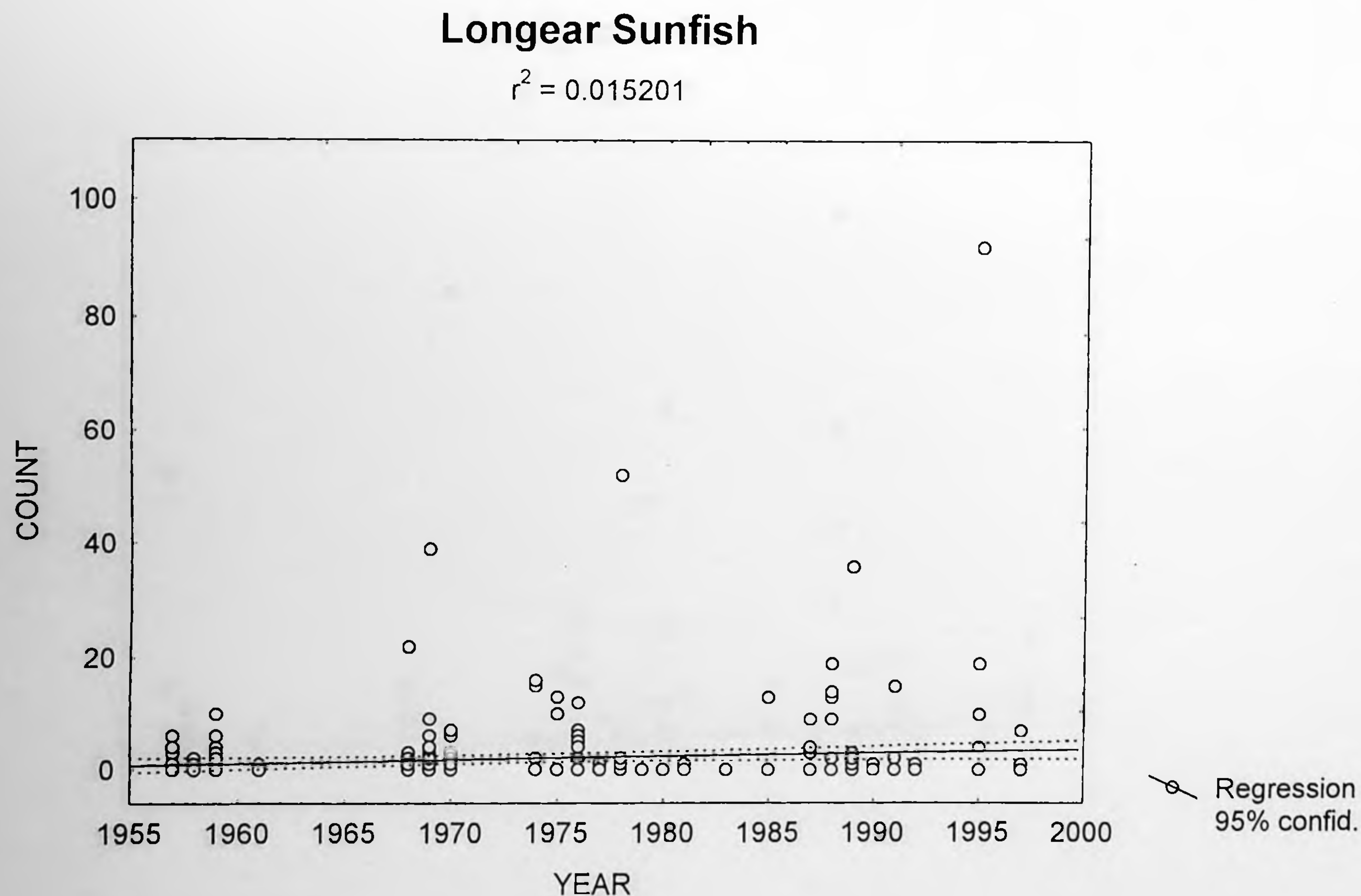

Fig. 14. Species showing a positive temporal/density correlation along the entire river.

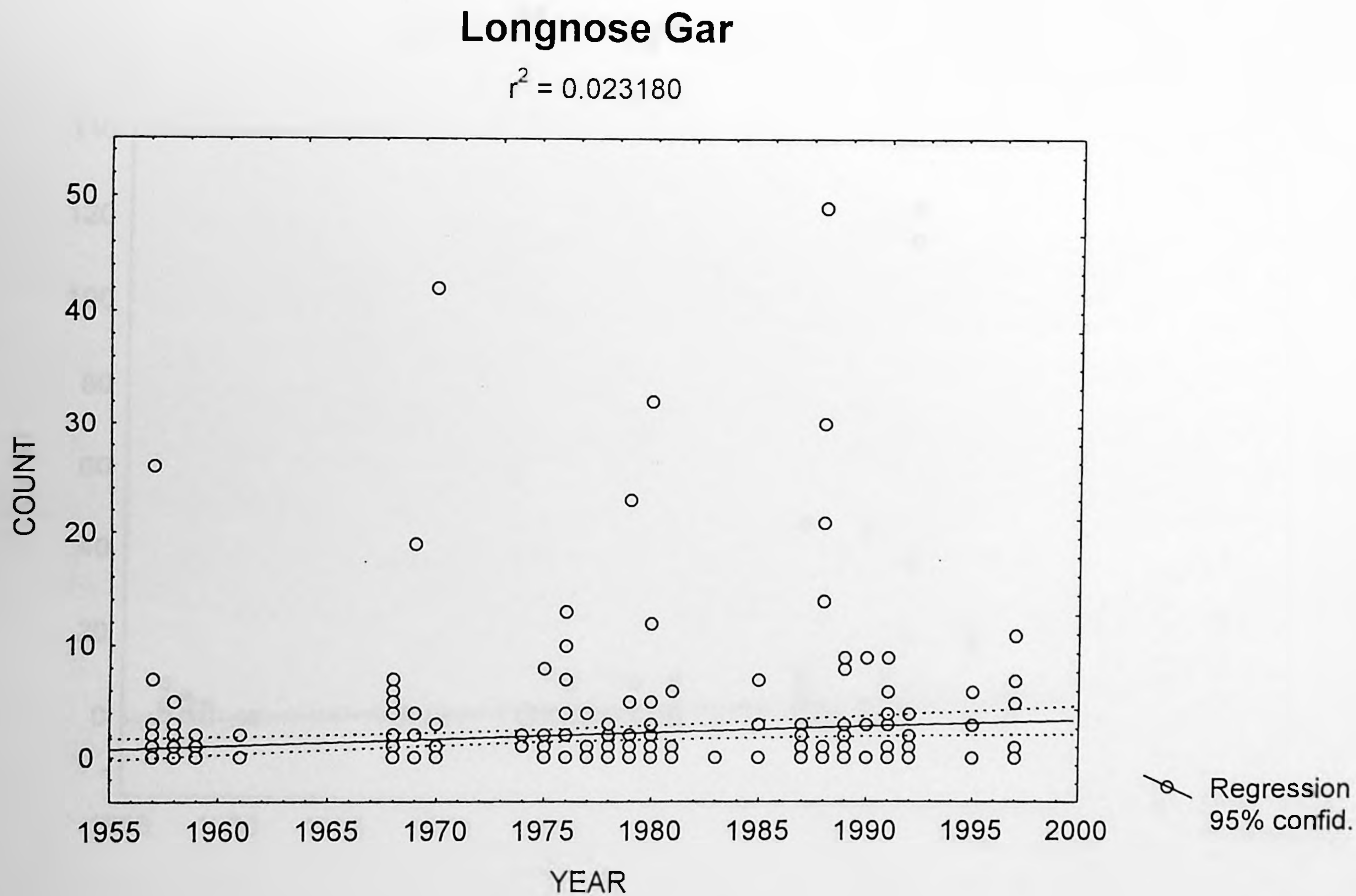

Fig. 15. Species showing a positive temporal/density correlation along the entire river.

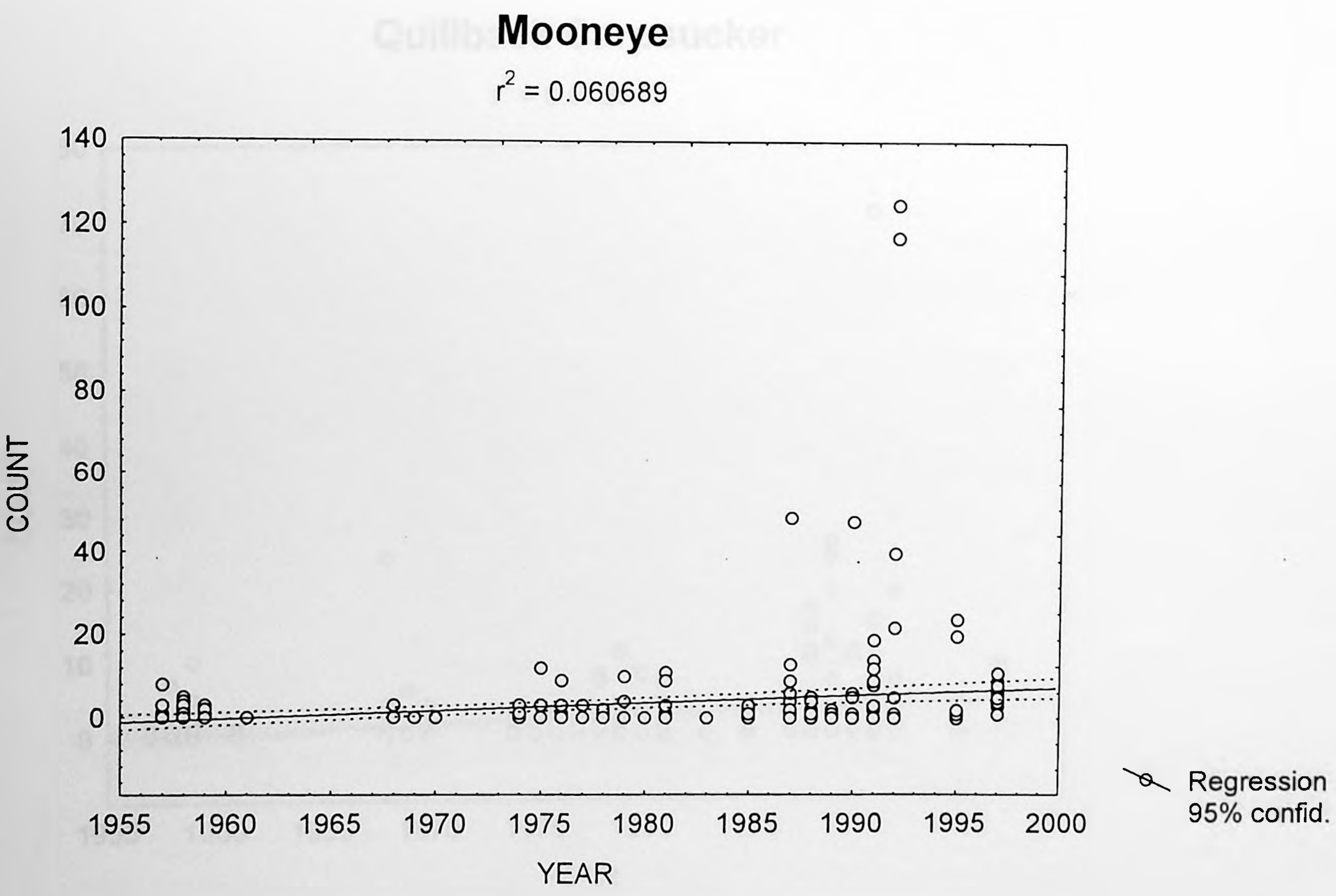

Fig. 16. Species showing a positive temporal/density correlation along the entire river.

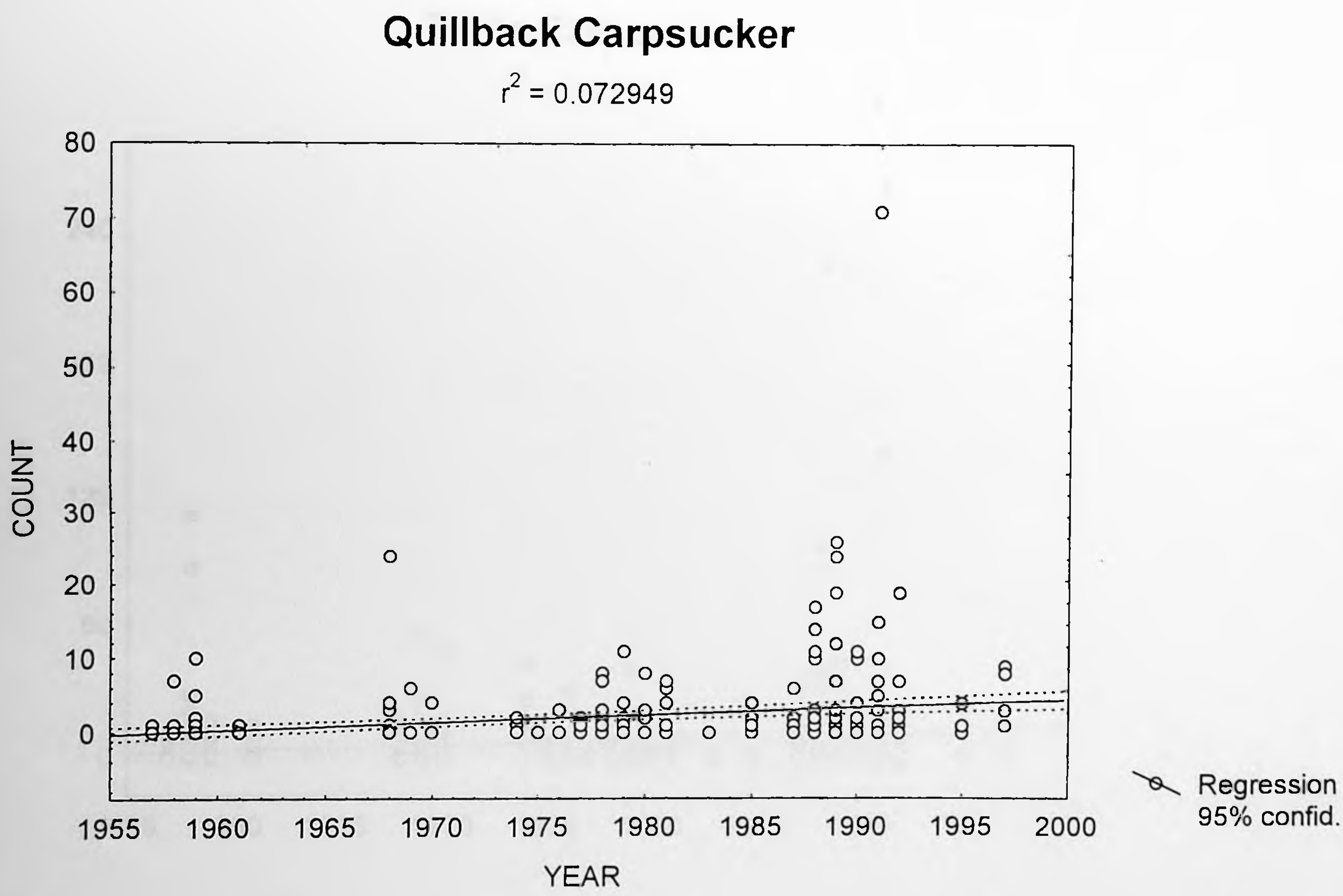

Fig. 17. Species showing a positive temporal/density correlation along the entire river.

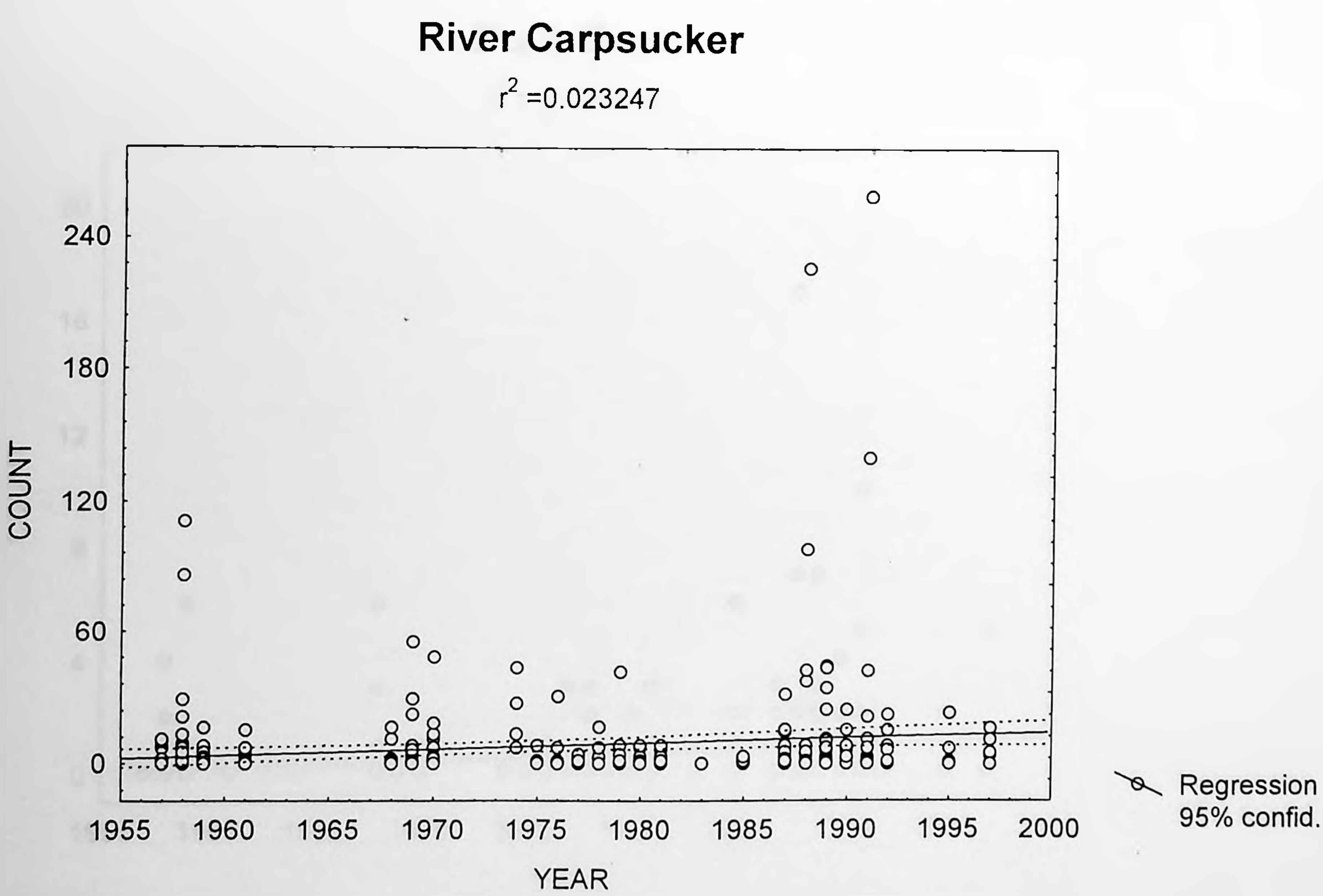

Fig. 18. Species showing a positive temporal/density correlation along the entire river.

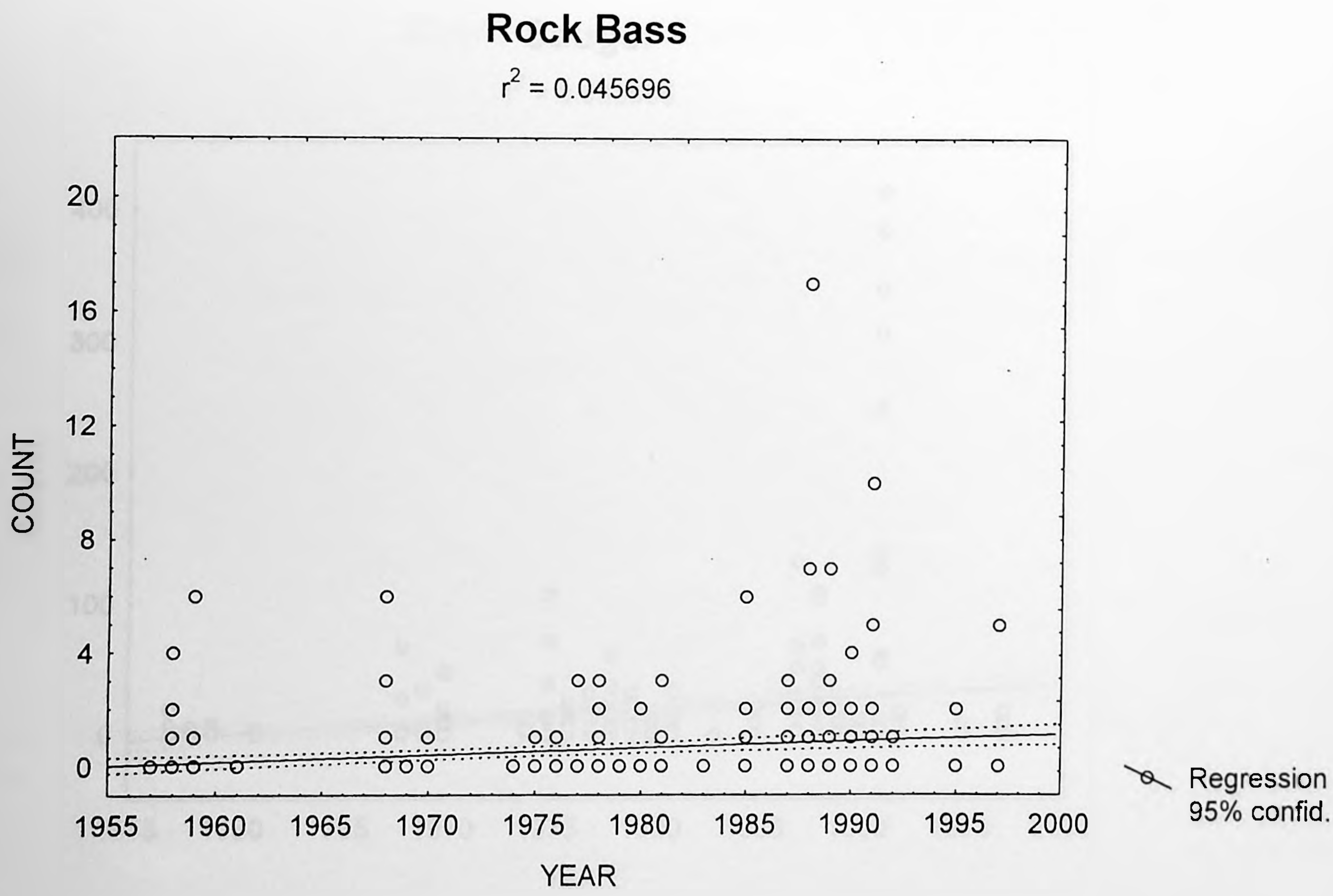

Fig. 19. Species showing a positive temporal/density correlation along the entire river.

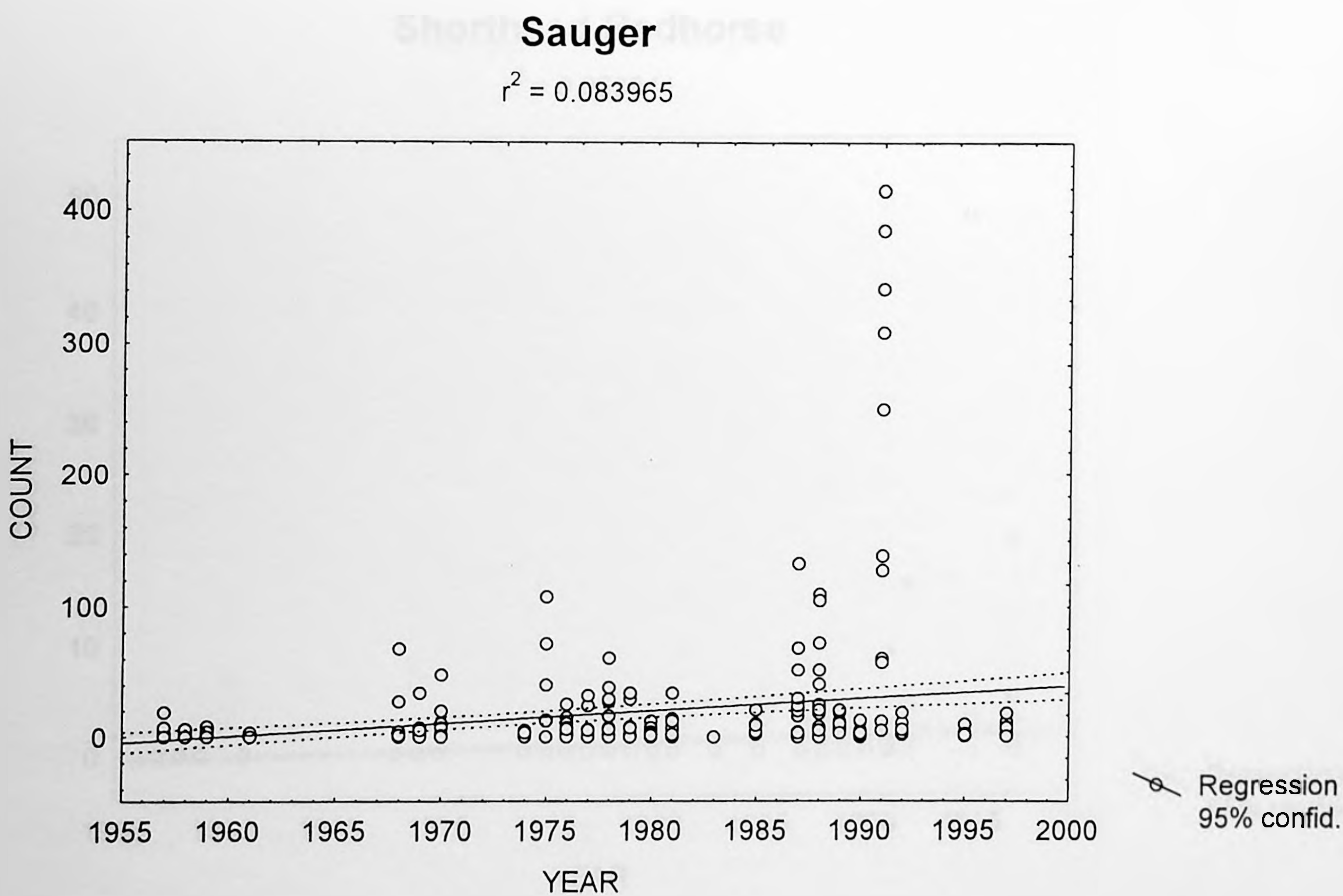

Fig. 20. Species showing a positive temporal/density correlation along the entire river.

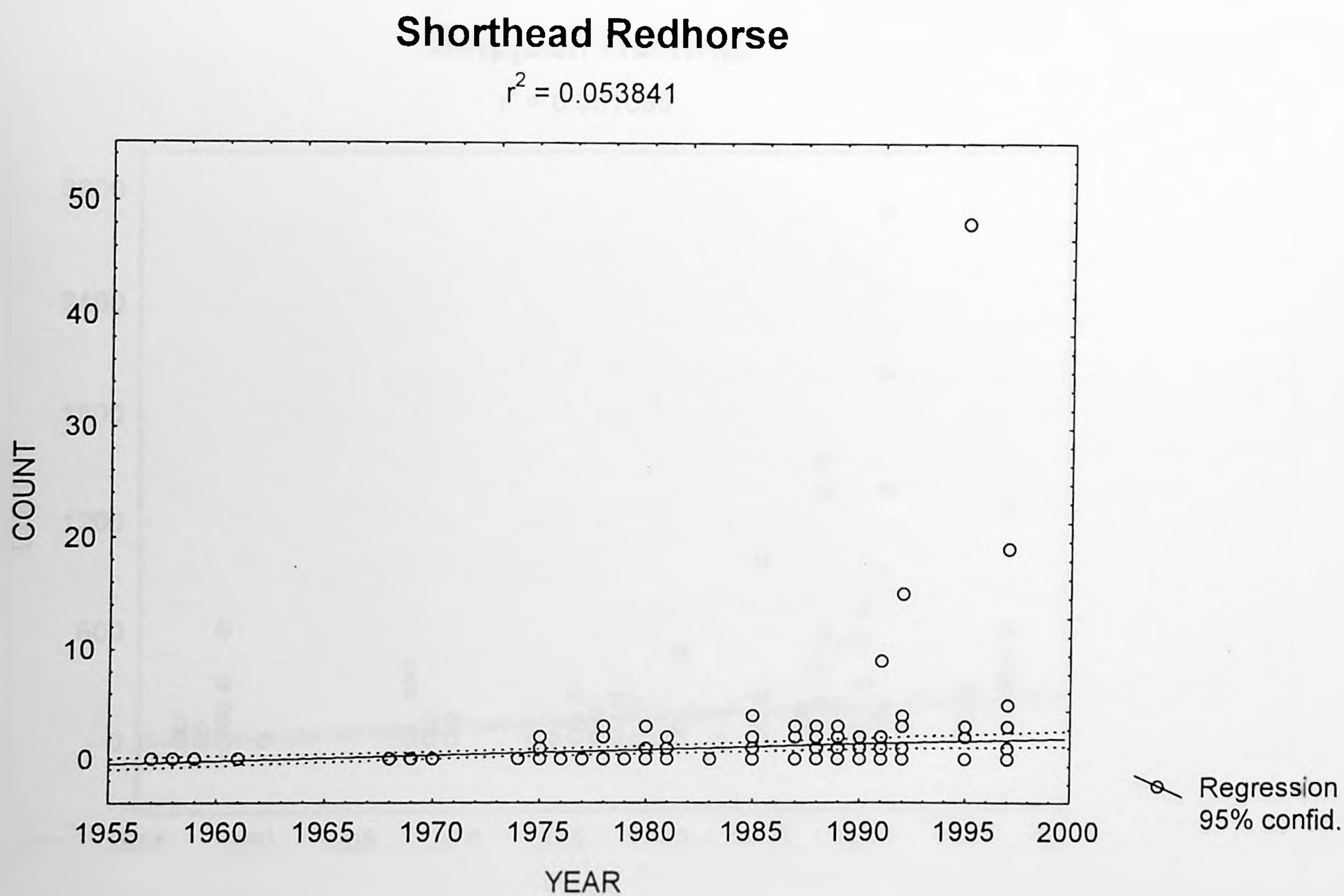

Fig. 21. Species showing a positive temporal/density correlation along the entire river.

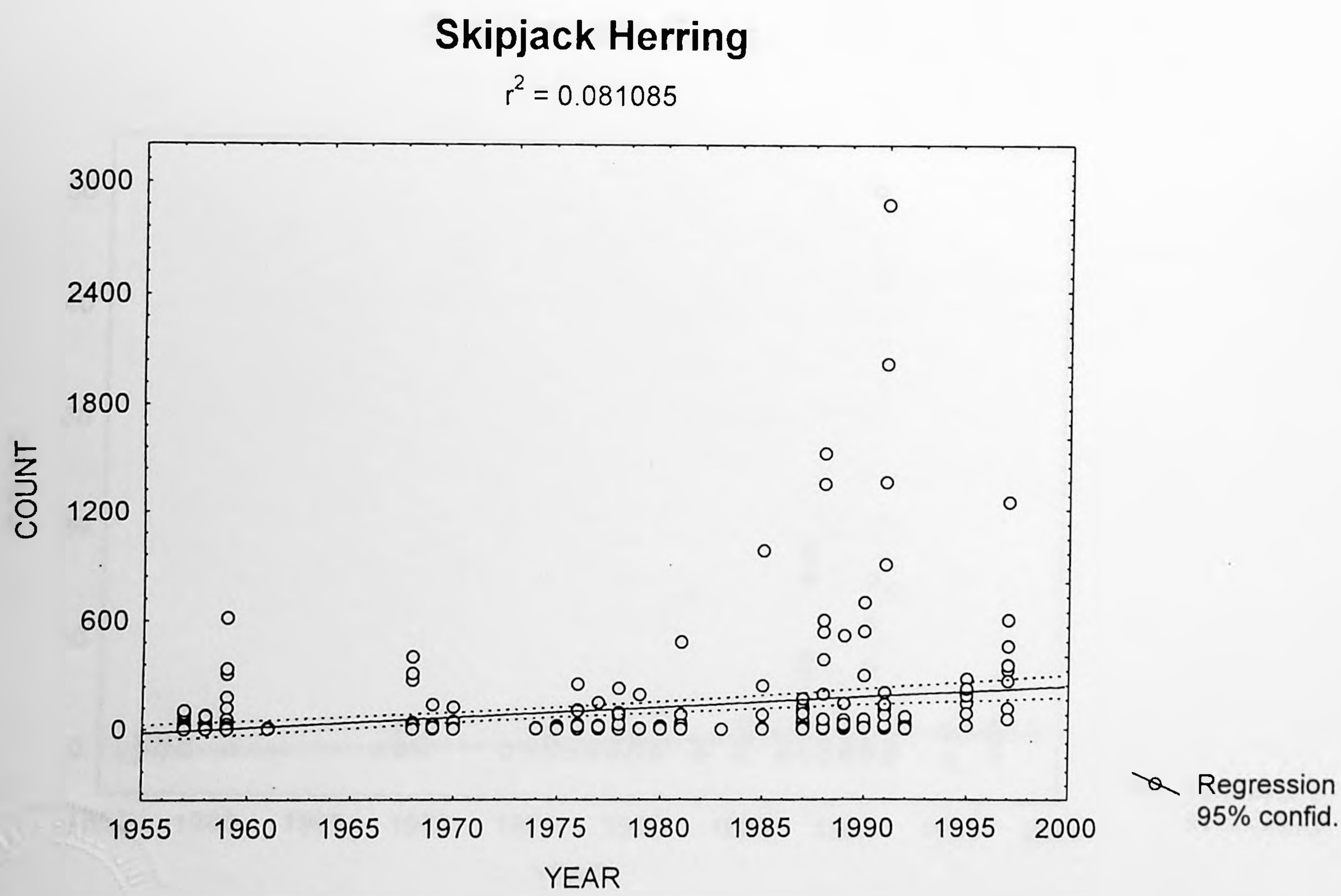

Fig. 22. Species showing a positive temporal/density correlation along the entire river.

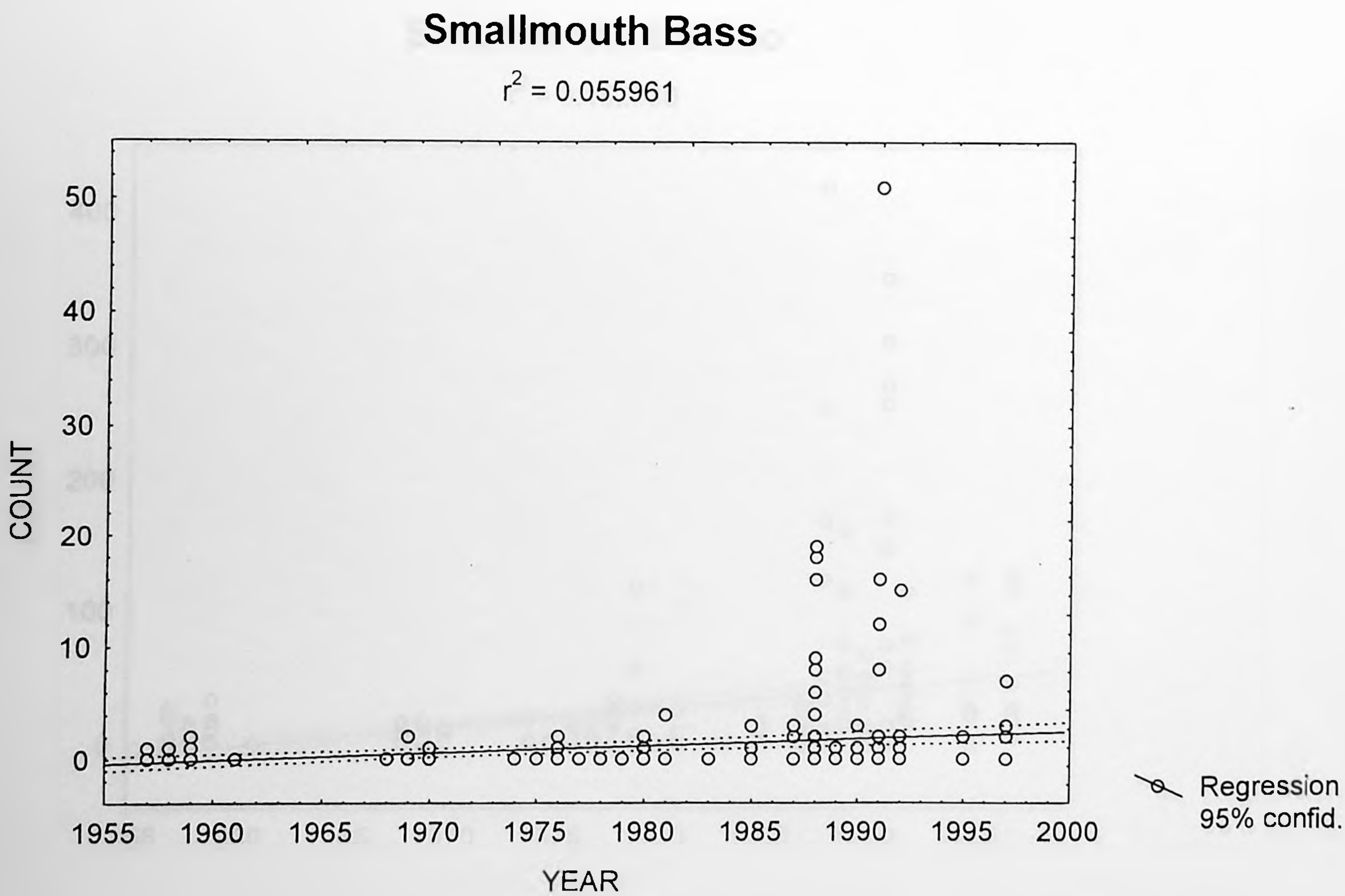

Fig. 23. Species showing a positive temporal/density correlation along the entire river.

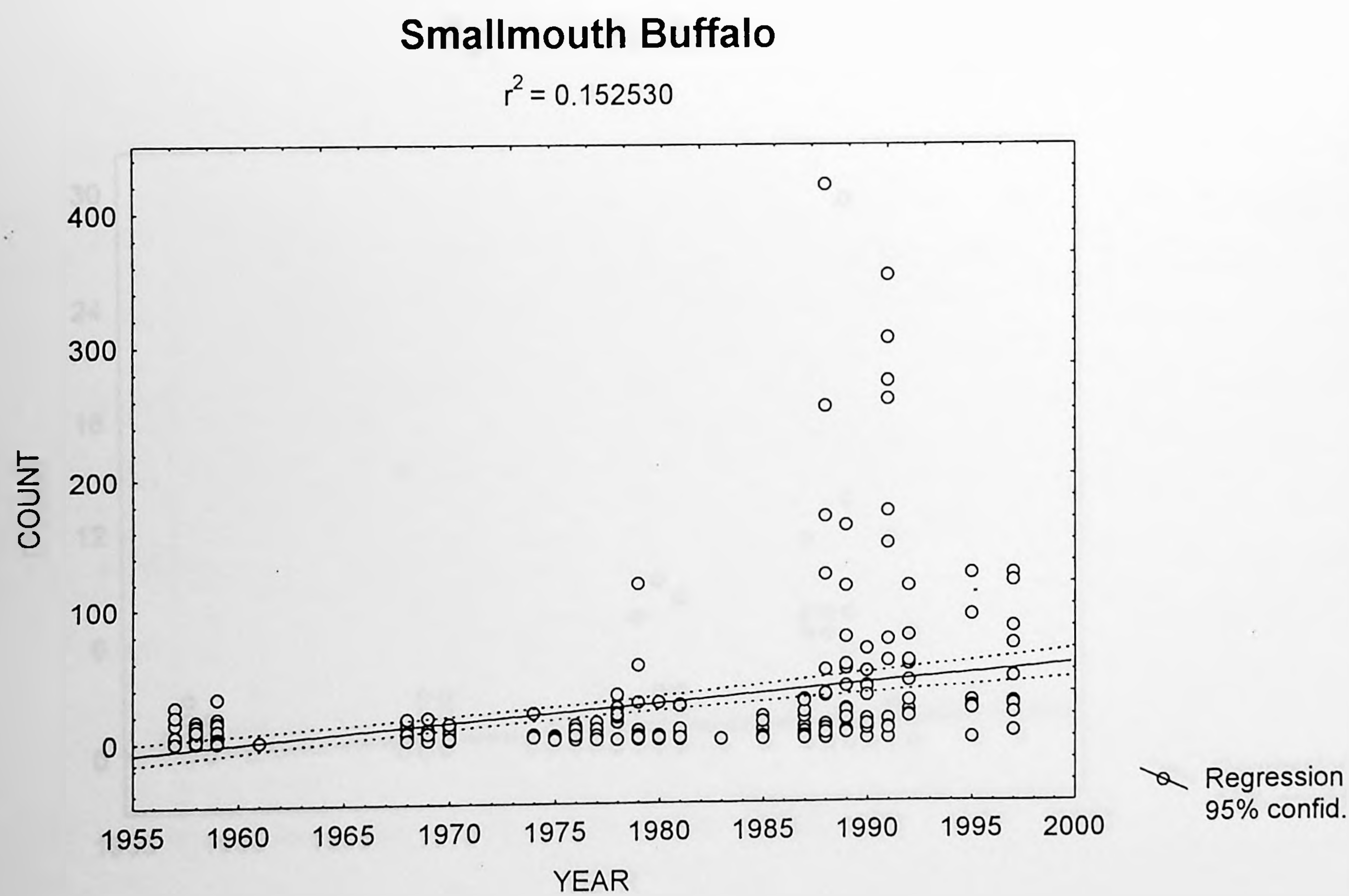

Fig. 24. Species showing a positive temporal/density correlation along the entire river.

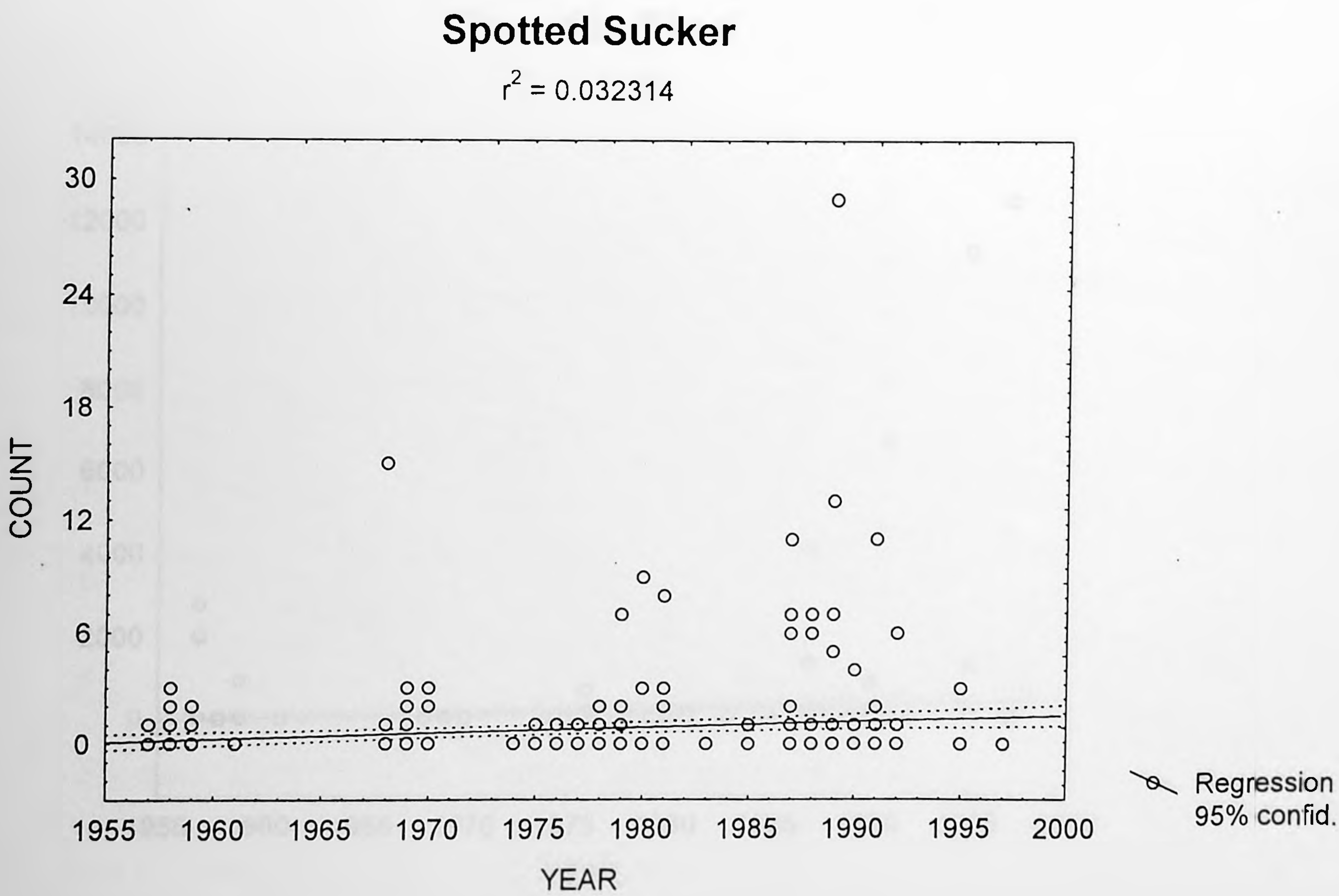

Fig. 25. Species showing a positive temporal/density correlation along the entire river.

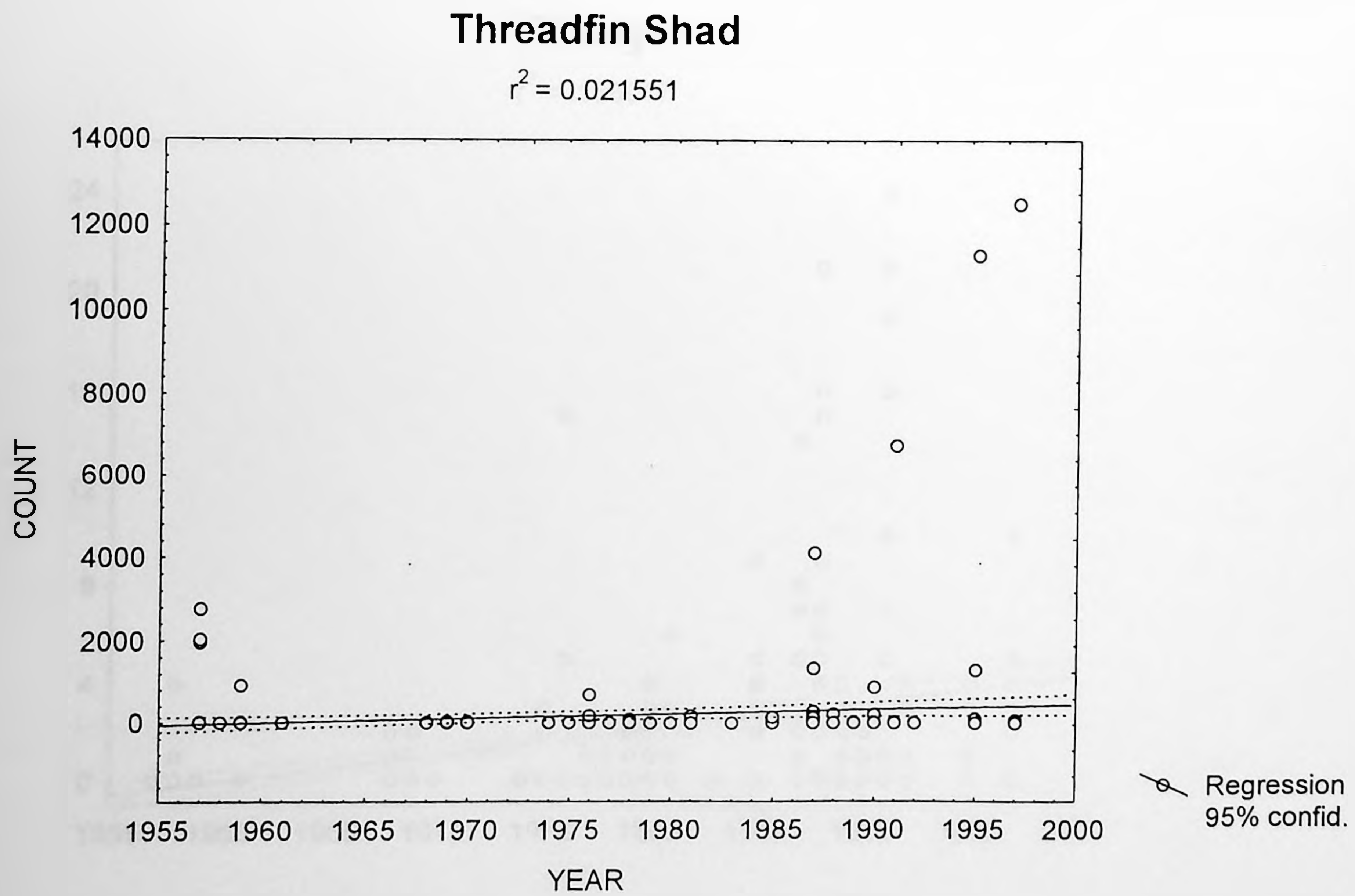

Fig. 26. Species showing a positive temporal/density correlation along the entire river.

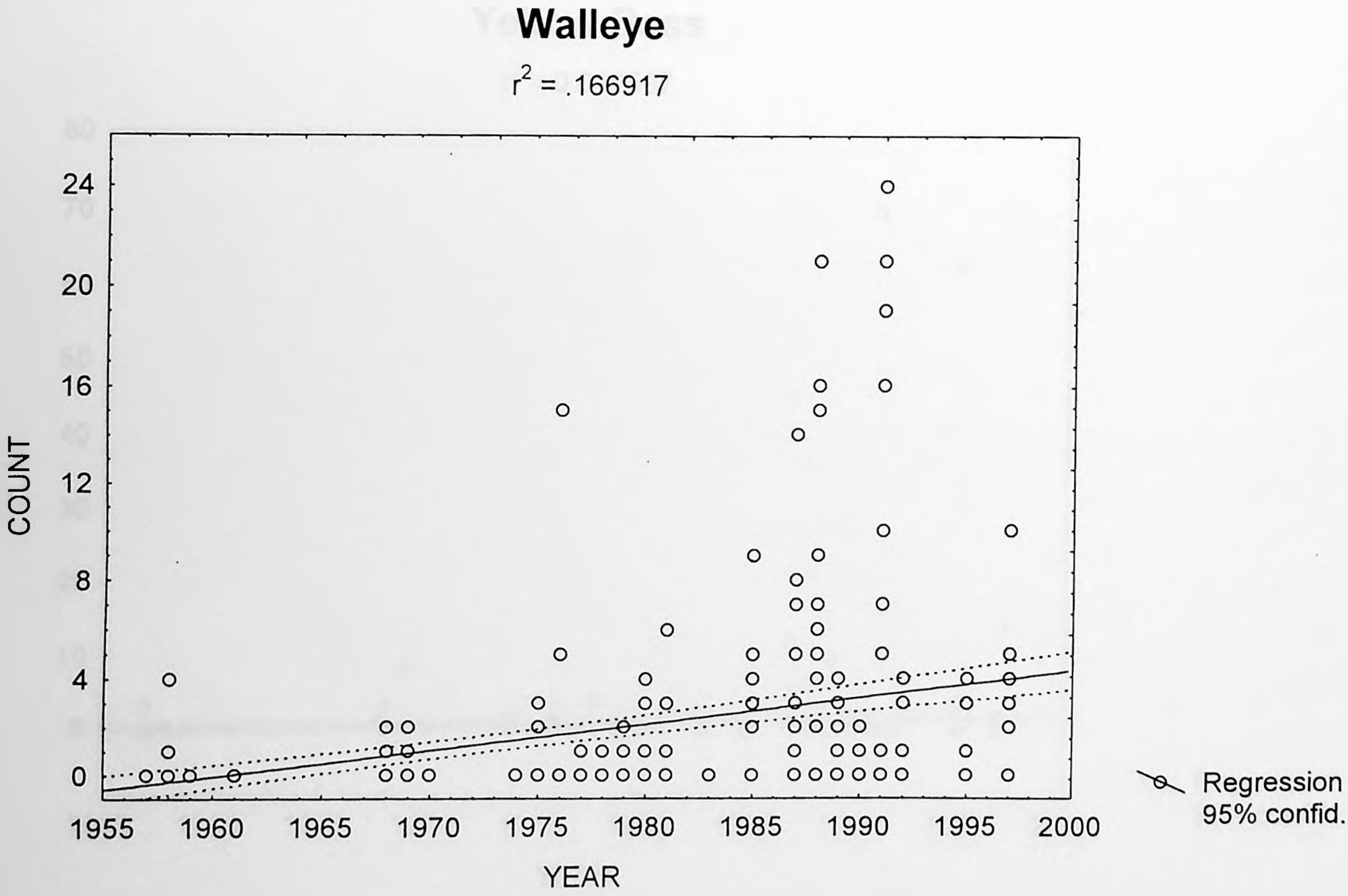

Fig. 27. Species showing a positive temporal/density correlation along the entire river.

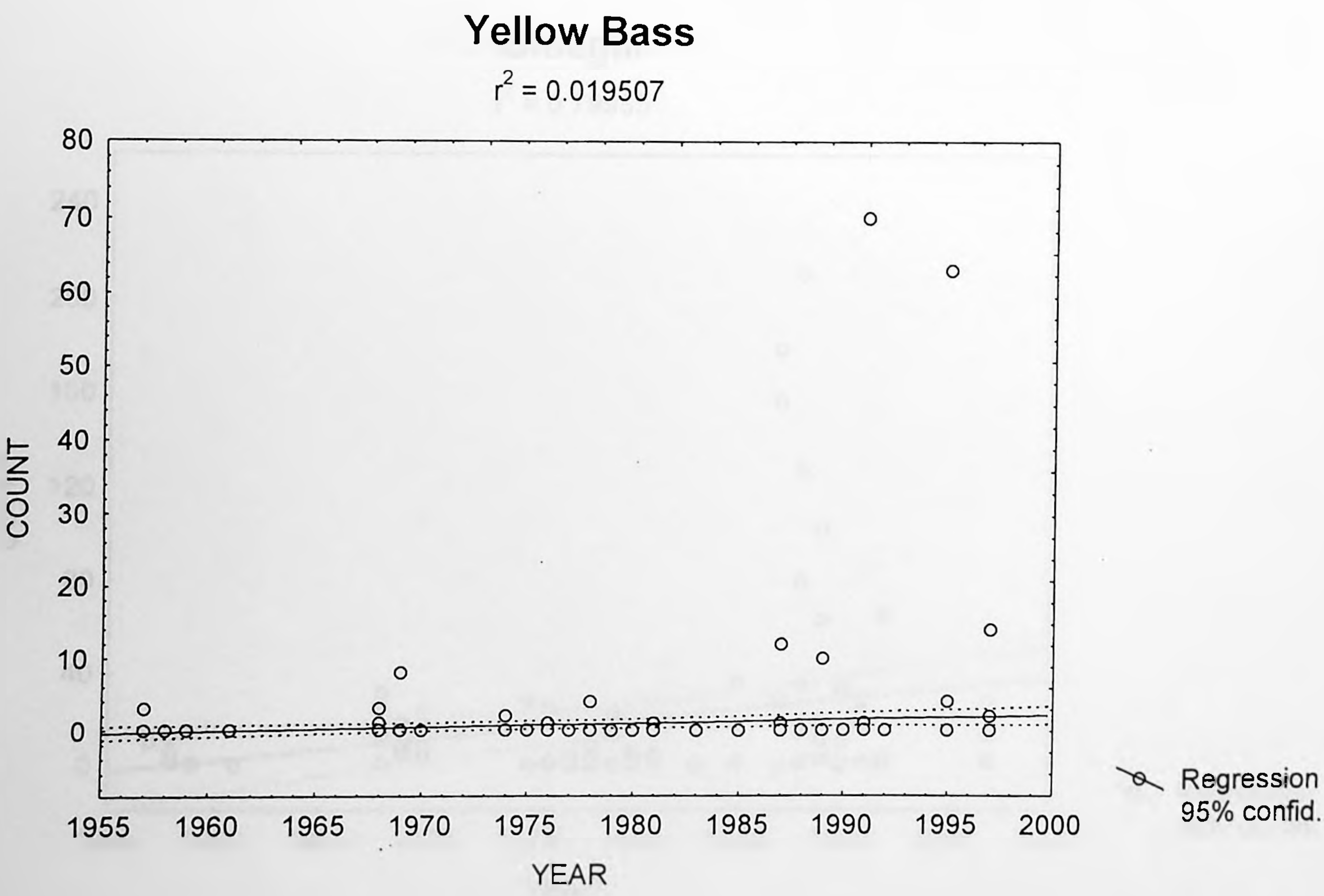

Fig. 28. Species showing a positive temporal/density correlation along the entire river.

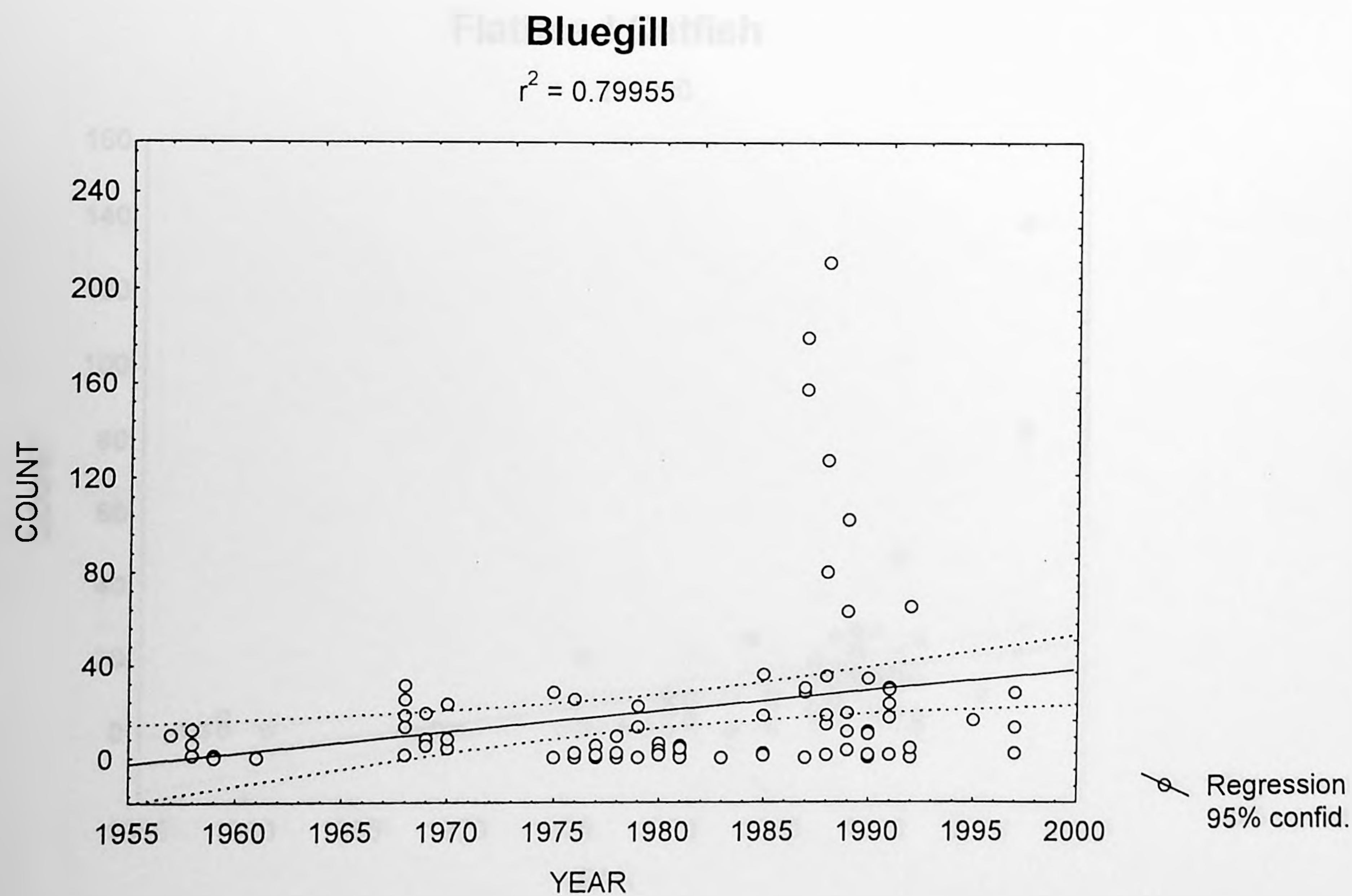

Fig. 29. Species showing a positive temporal/density correlation along the upper river section.

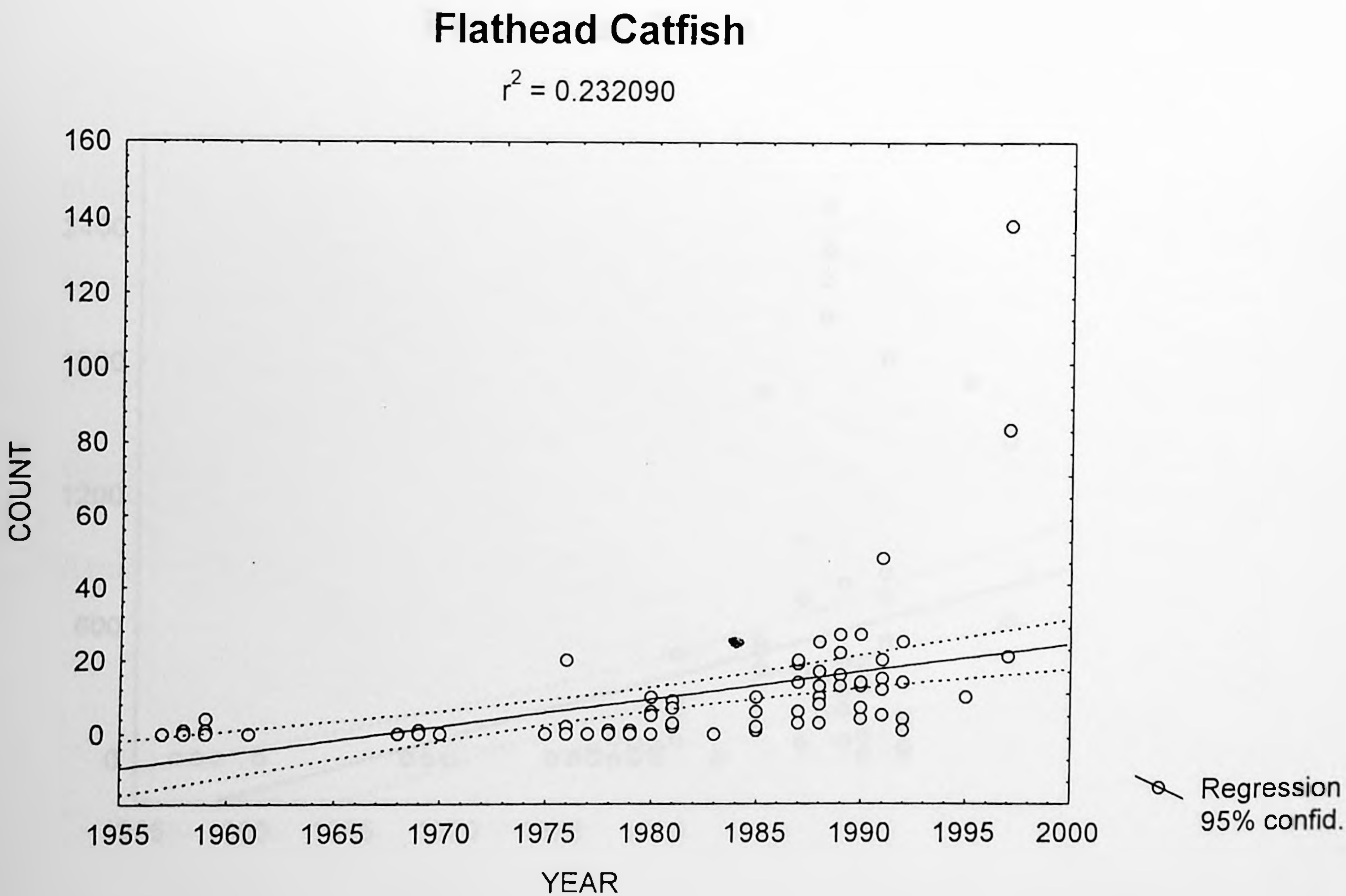

Fig. 30. Species showing a positive temporal/density correlation along the upper river section.

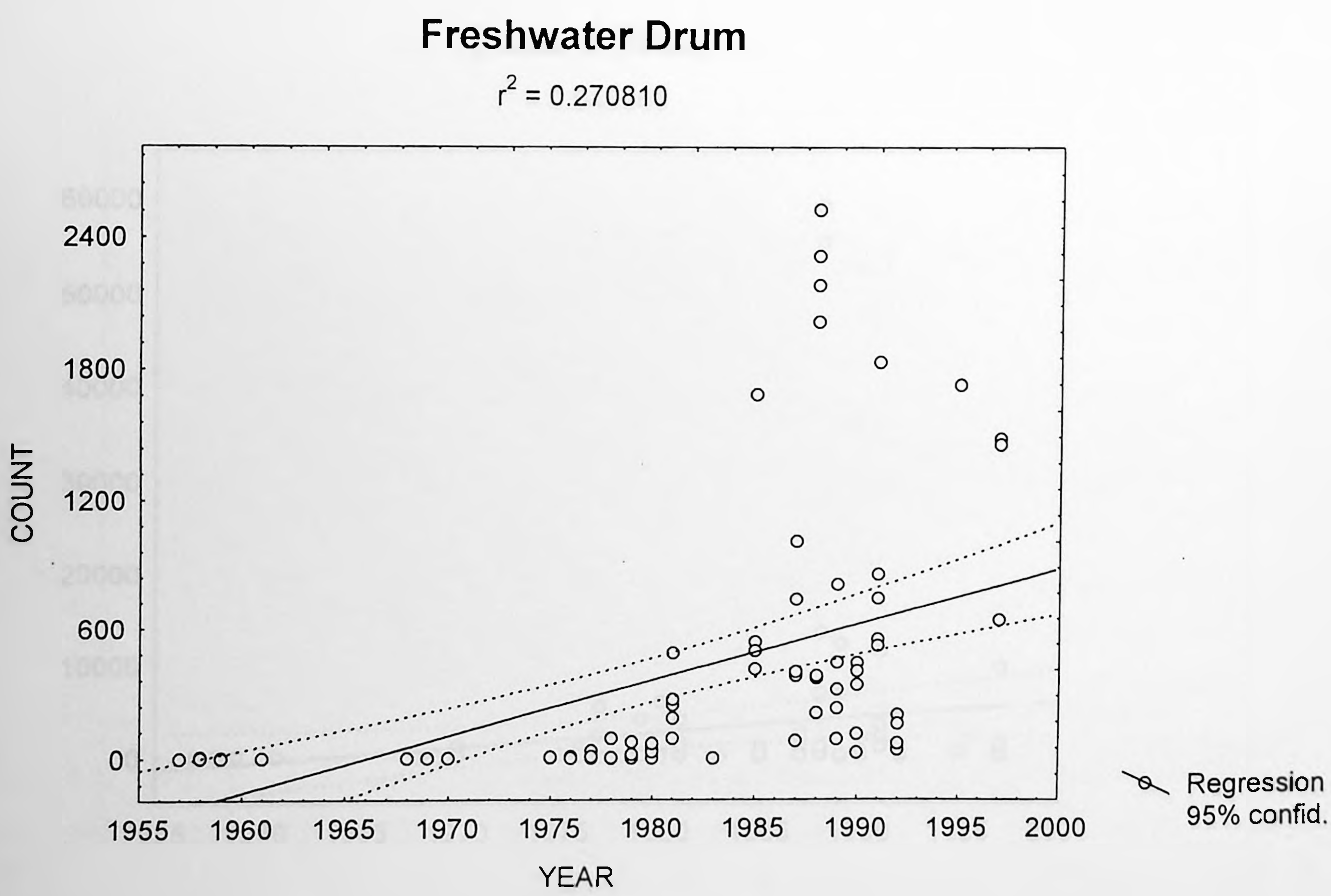

Fig. 31. Species showing a positive temporal/density correlation along the upper river section.

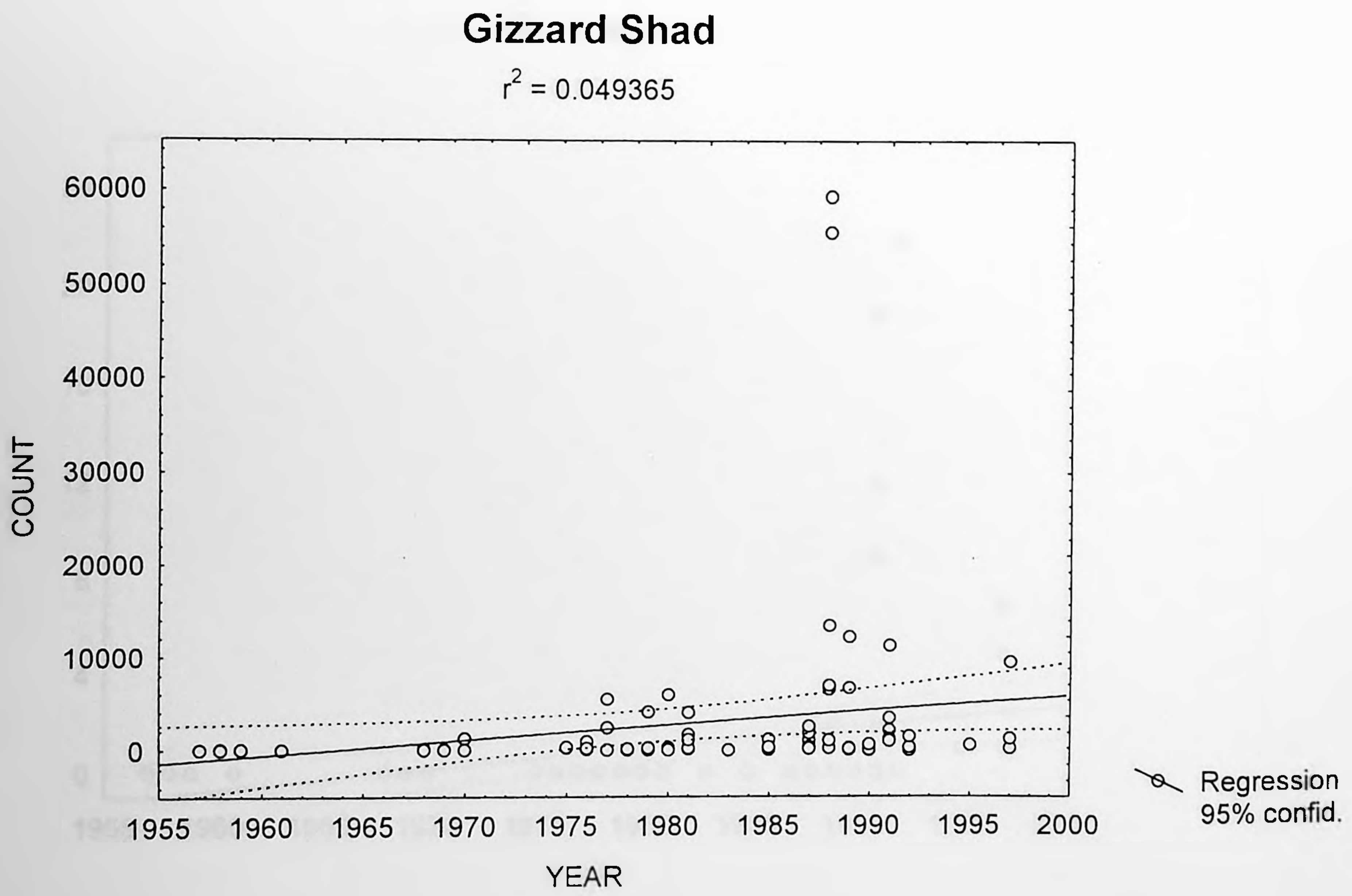

Fig. 32. Species showing a positive temporal/density correlation along the upper river section.

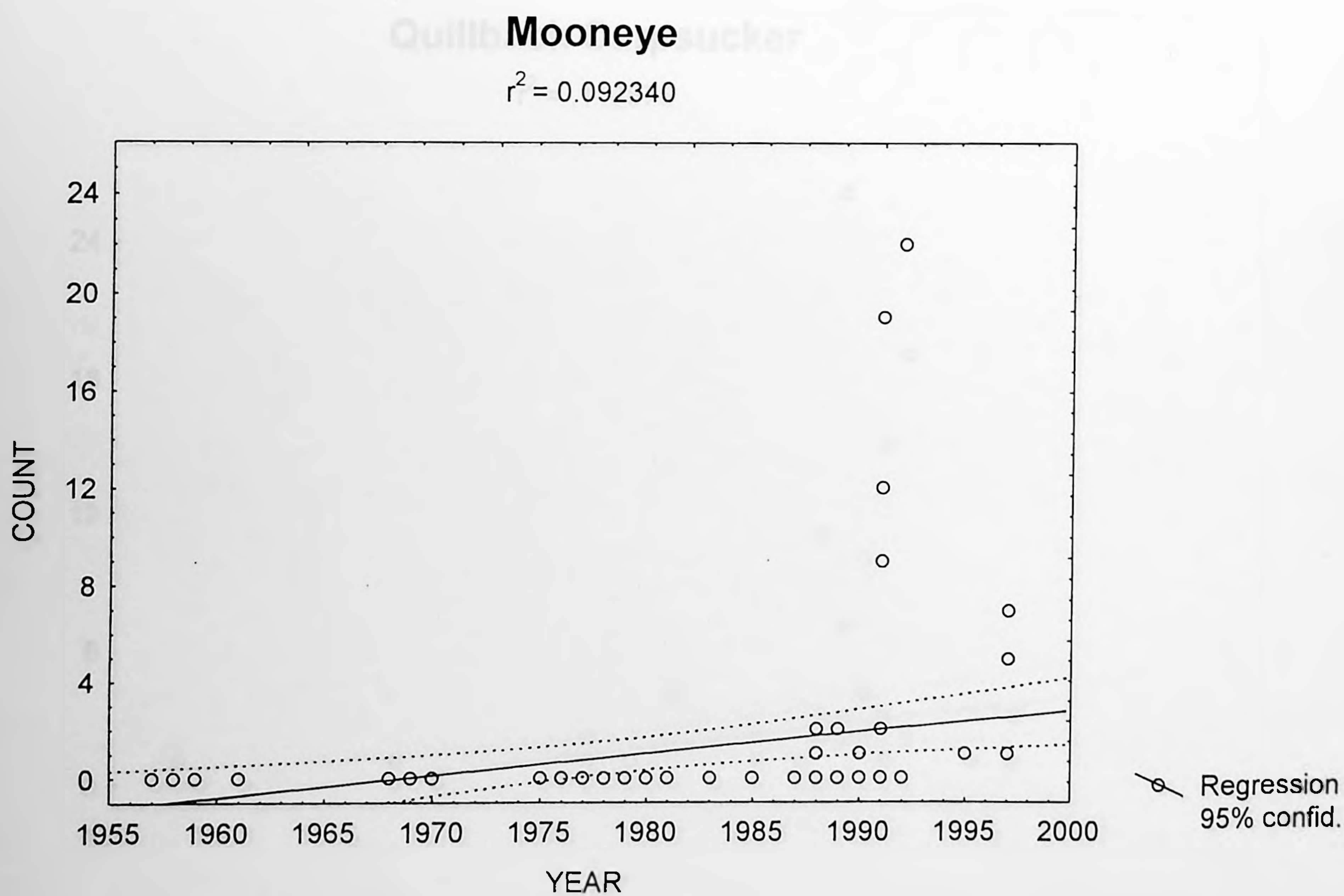

Fig. 33. Species showing a positive temporal/density correlation along the upper river section.

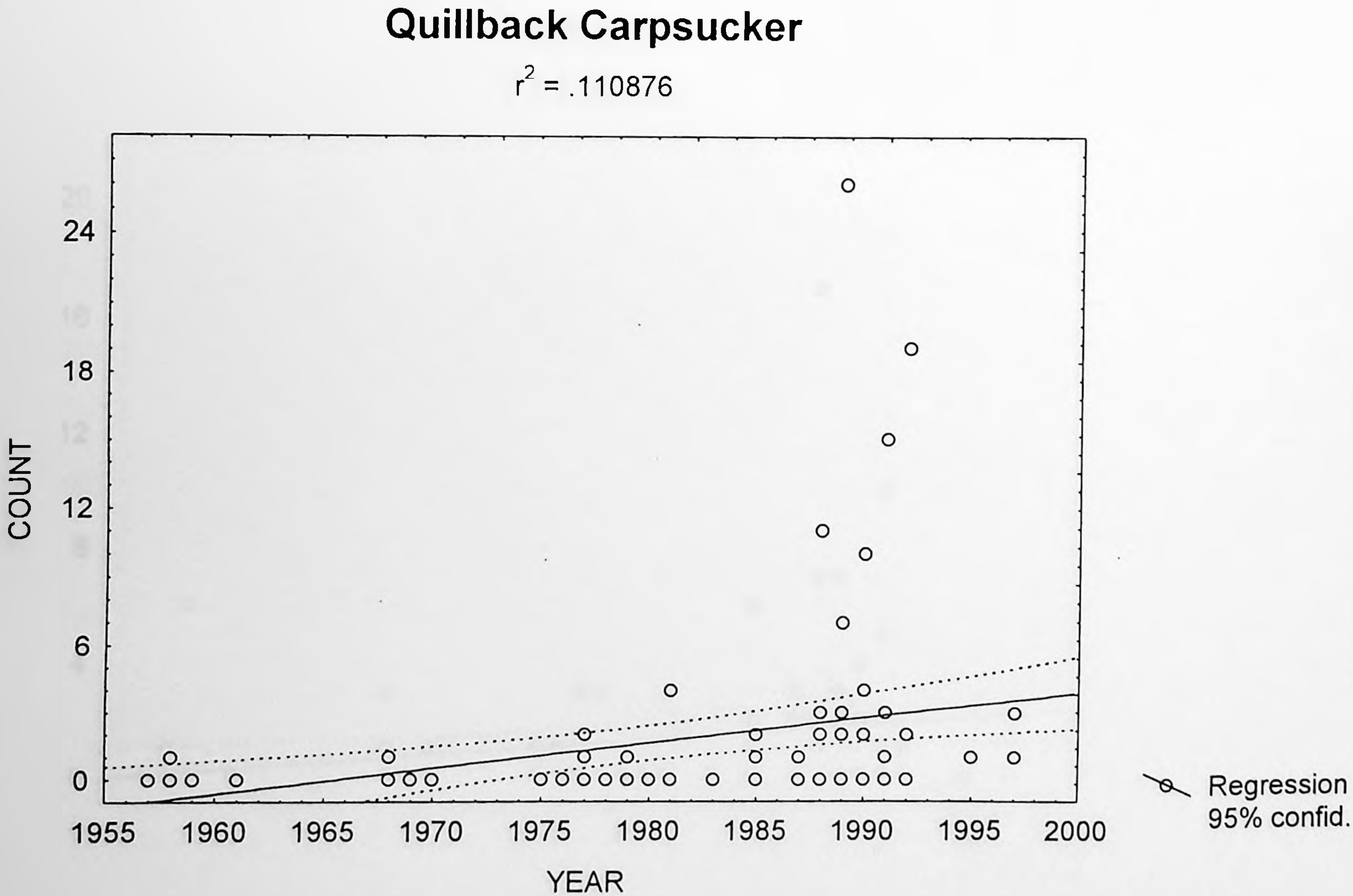

Fig. 34. Species showing a positive temporal/density correlation along the upper river section.

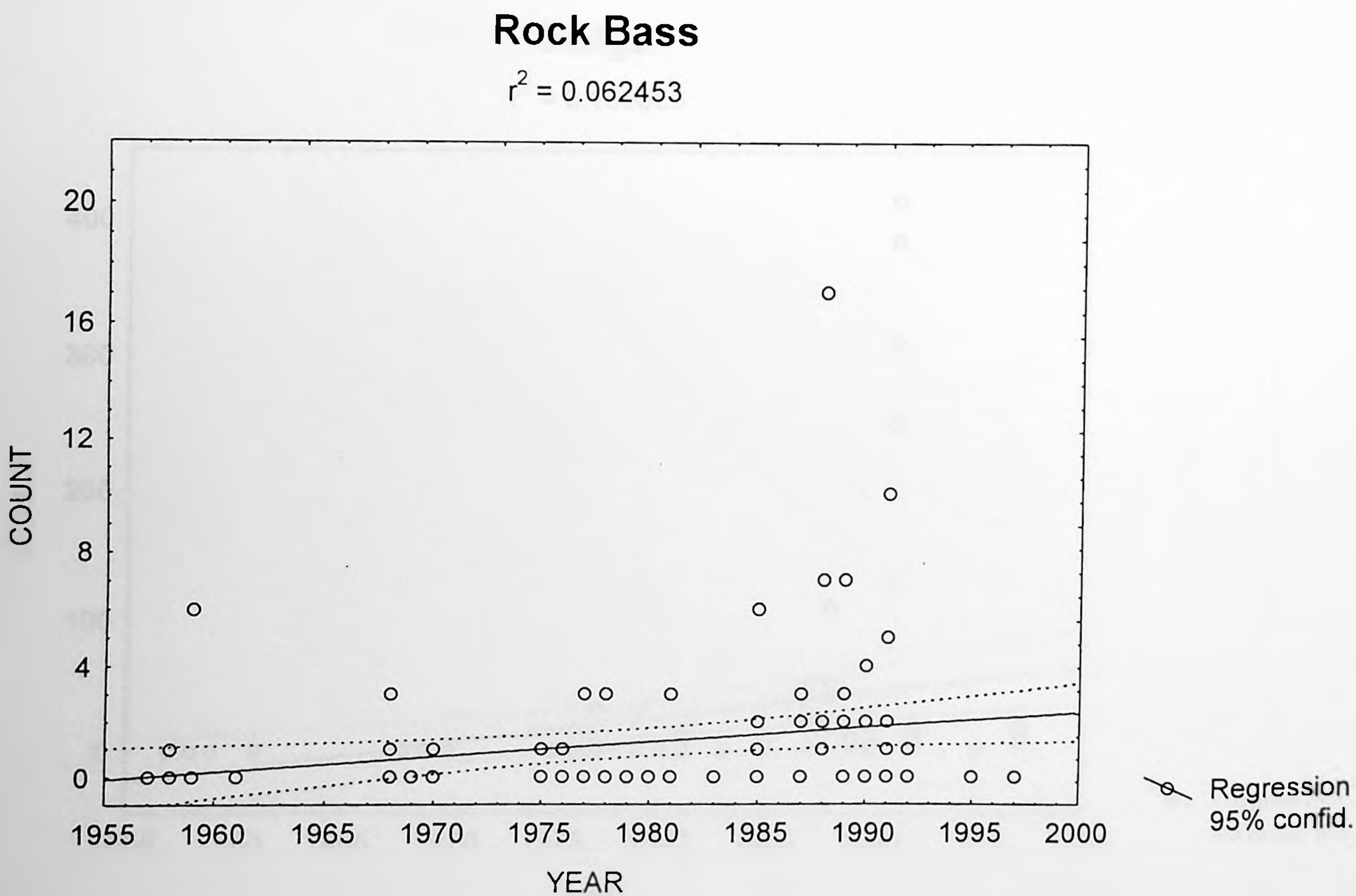

Fig. 35. Species showing a positive temporal/density correlation along the upper river section.

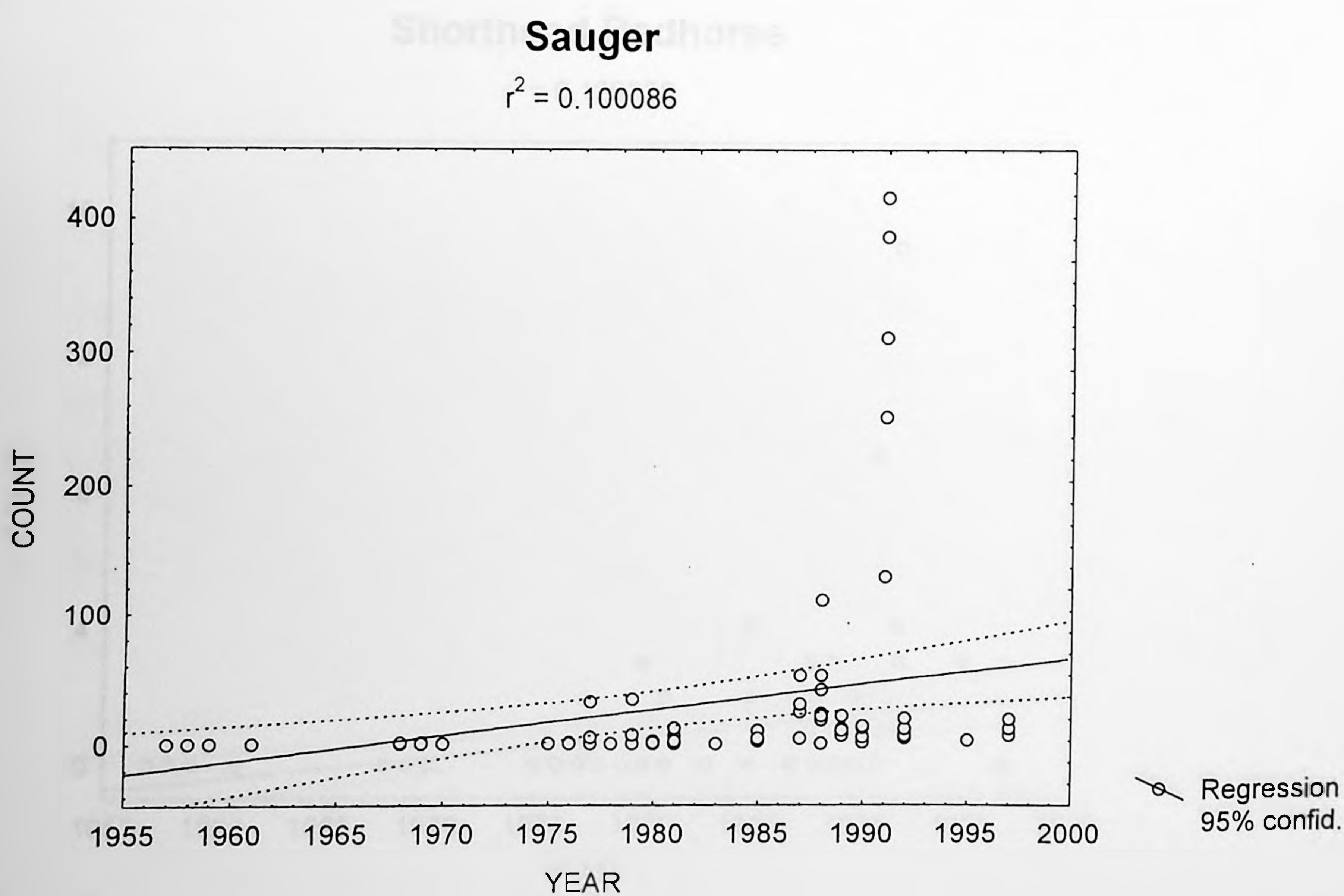

Fig. 36. Species showing a positive temporal/density correlation along the upper river section.

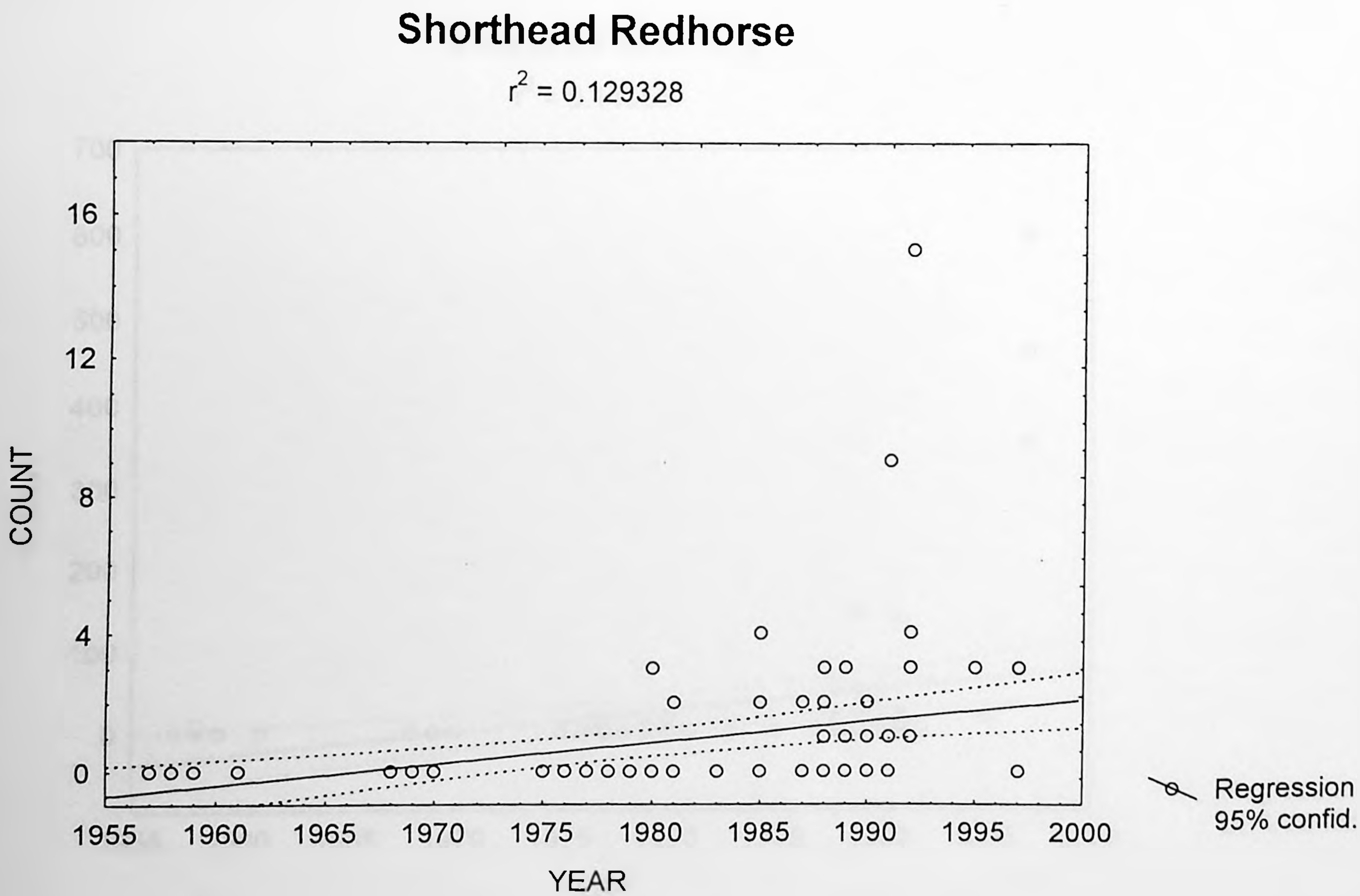

Fig. 37. Species showing a positive temporal/density correlation along the upper river section.

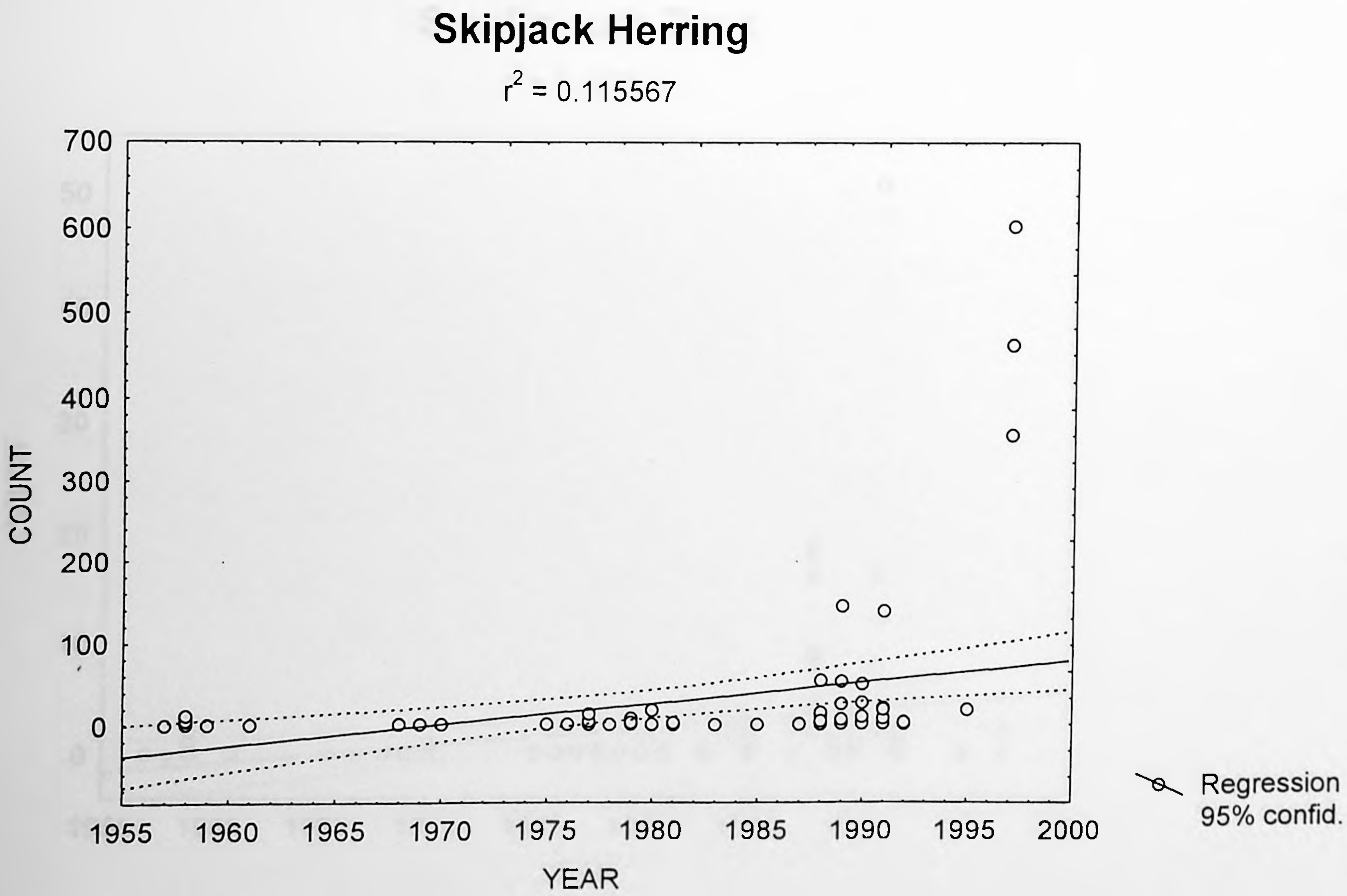

Fig. 38. Species showing a positive temporal/density correlation along the upper river section.

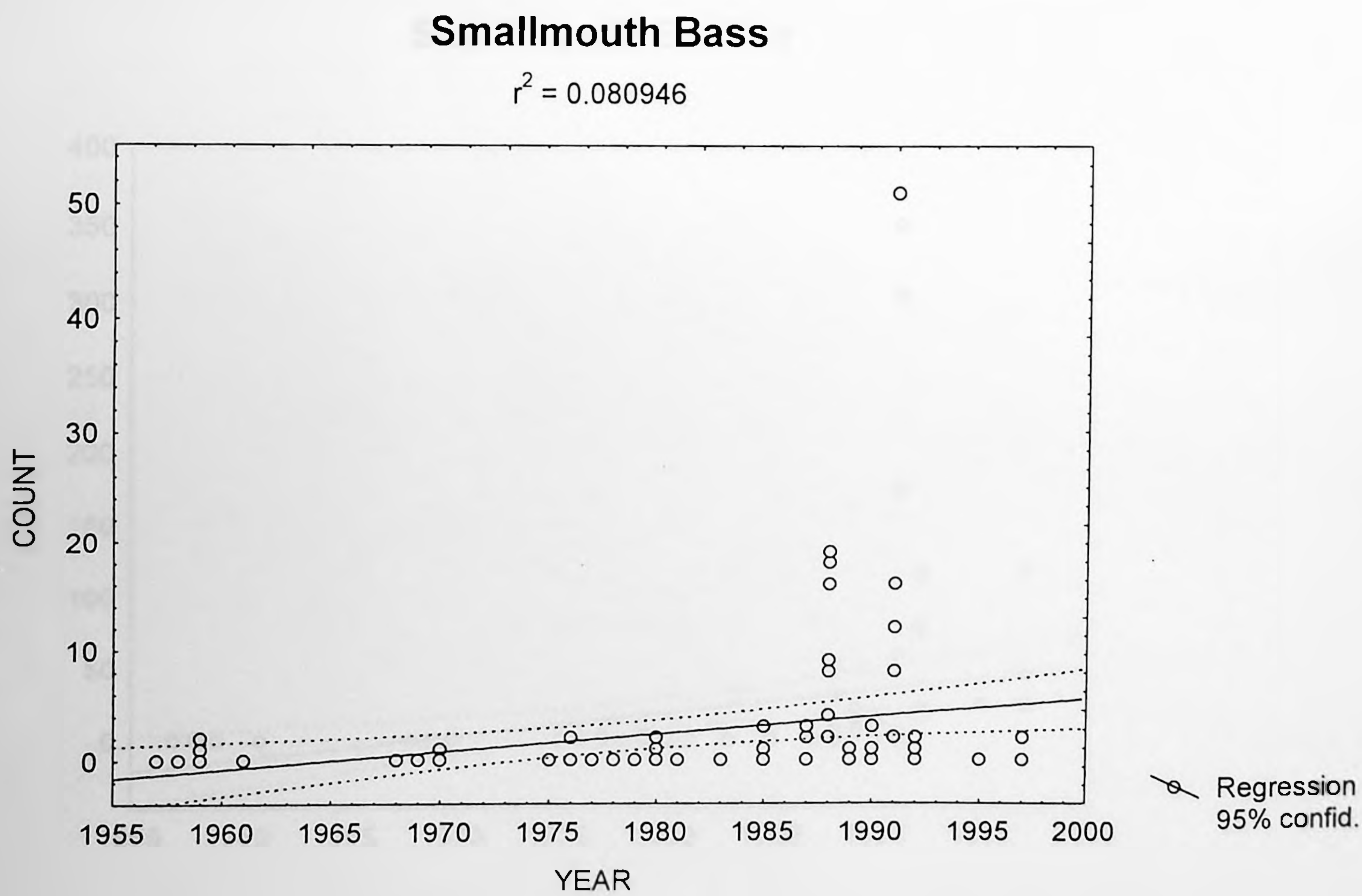

Fig. 39. Species showing a positive temporal/density correlation along the upper river section.

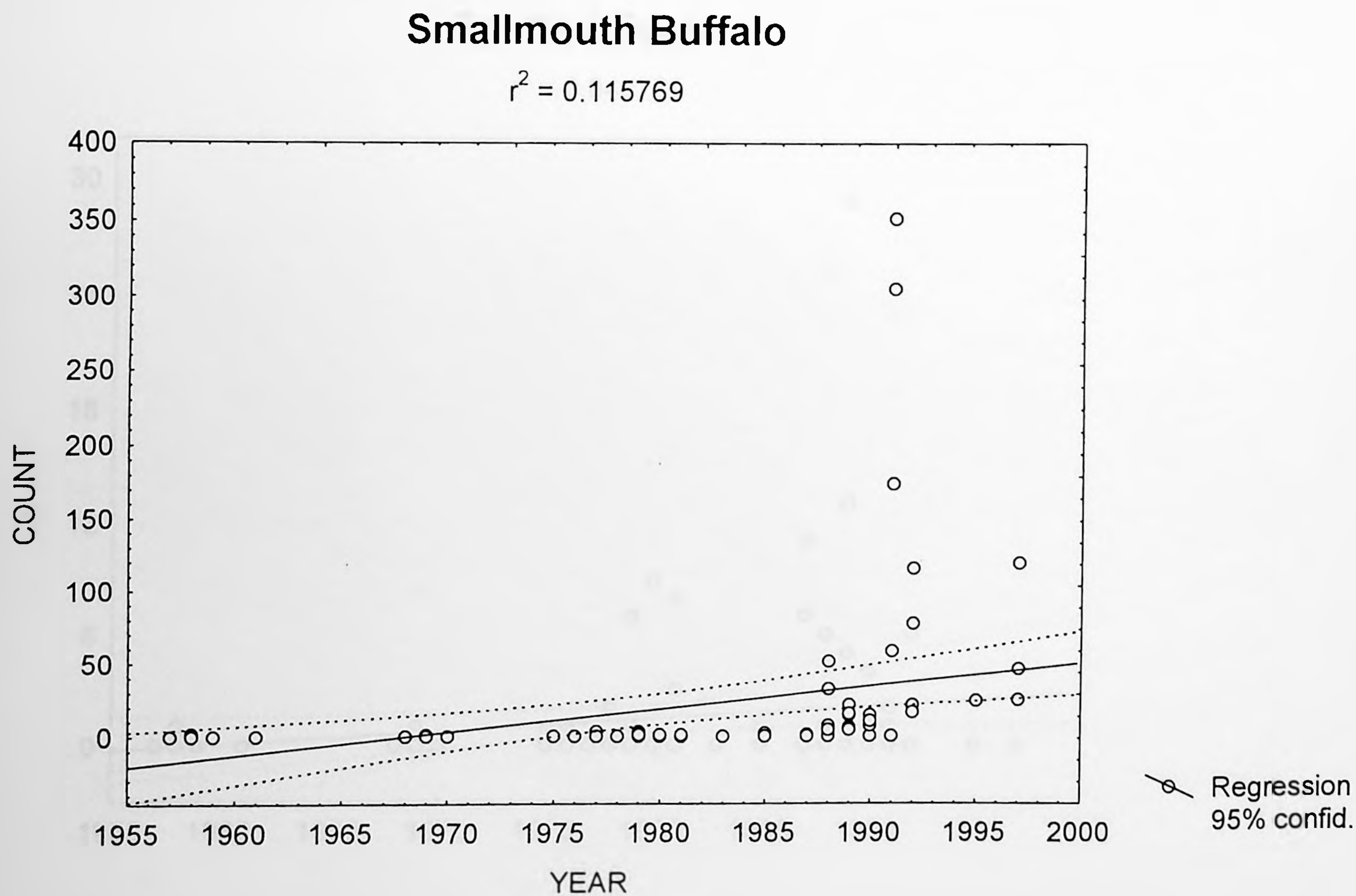

Fig. 40. Species showing a positive temporal/density correlation along the upper river section.

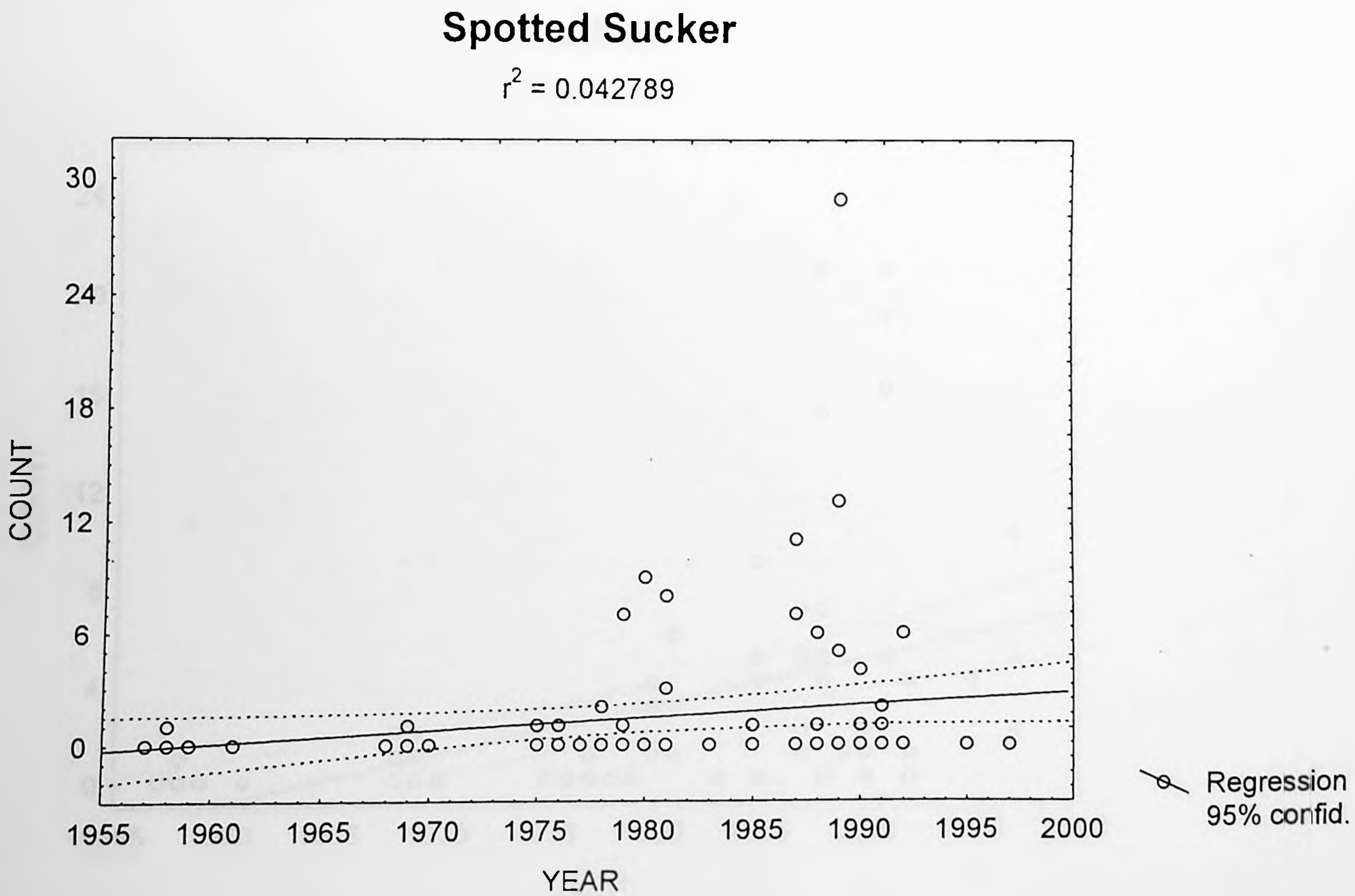

Fig. 41. Species showing a positive temporal/density correlation along the upper river section.

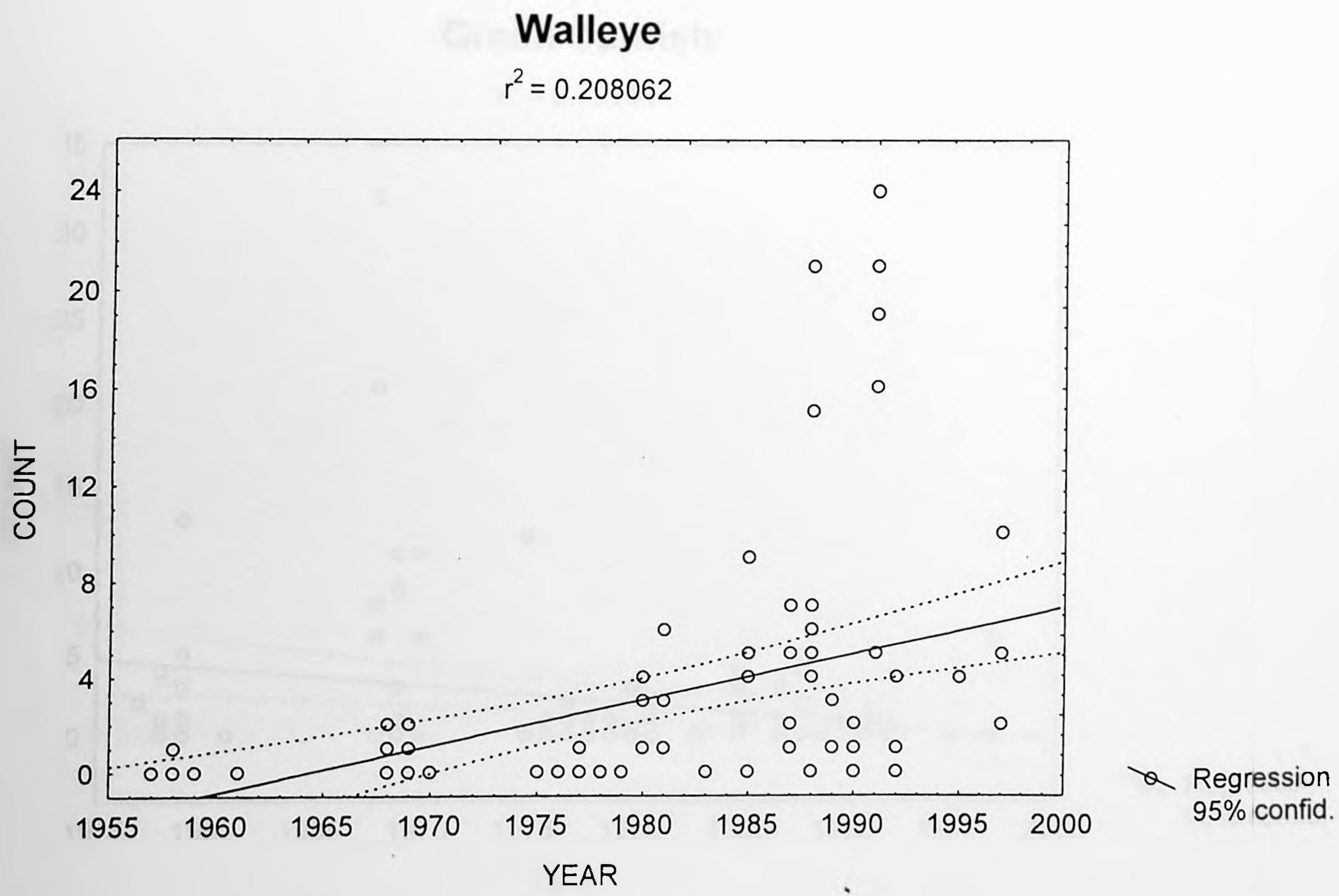

Fig. 42. Species showing a positive temporal/density correlation along the upper river section.

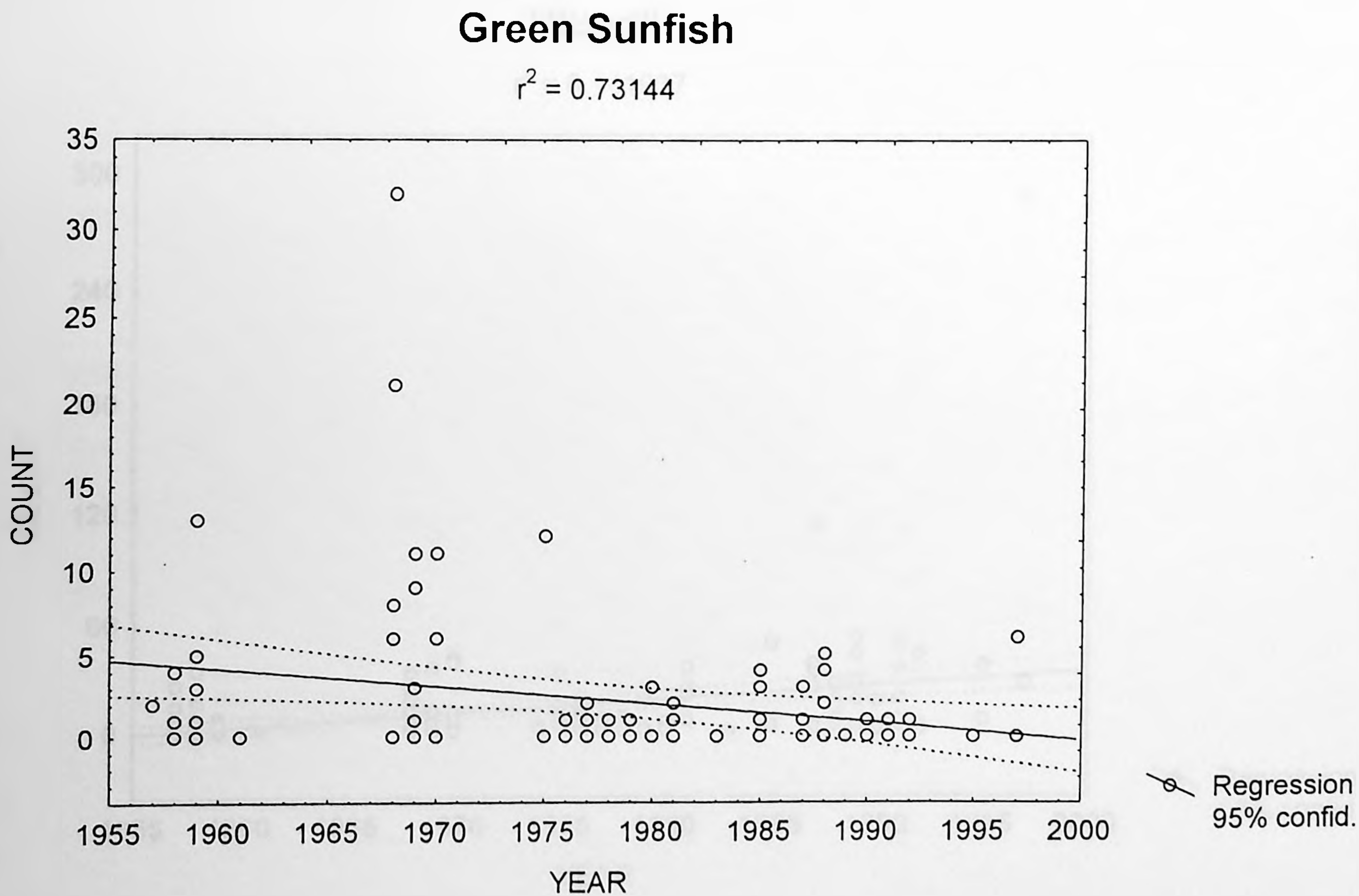

Fig. 43. Species showing a negative temporal/density correlation along the upper river section.

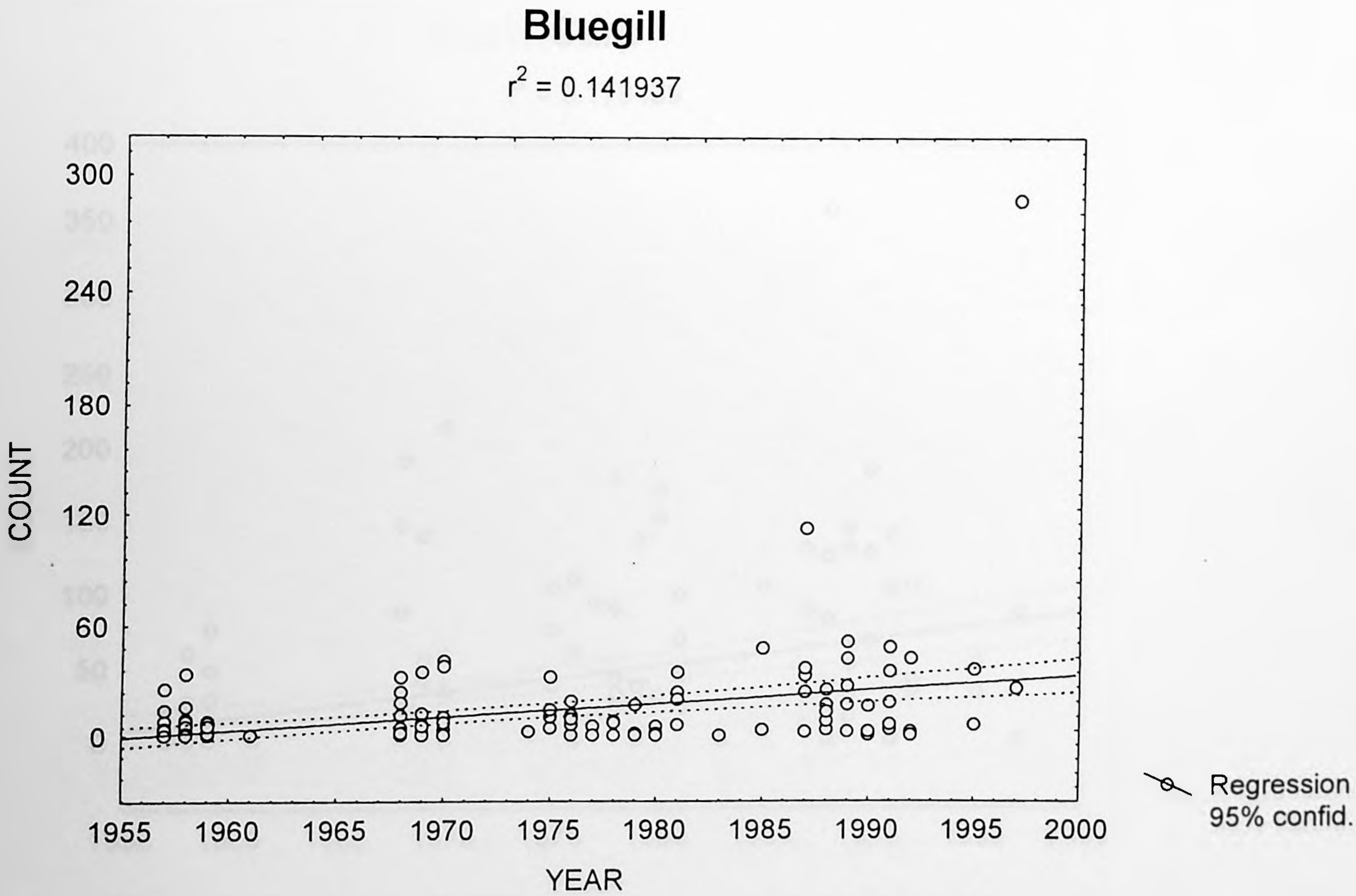

Fig. 44. Species showing a positive temporal/density correlation along the middle river section.

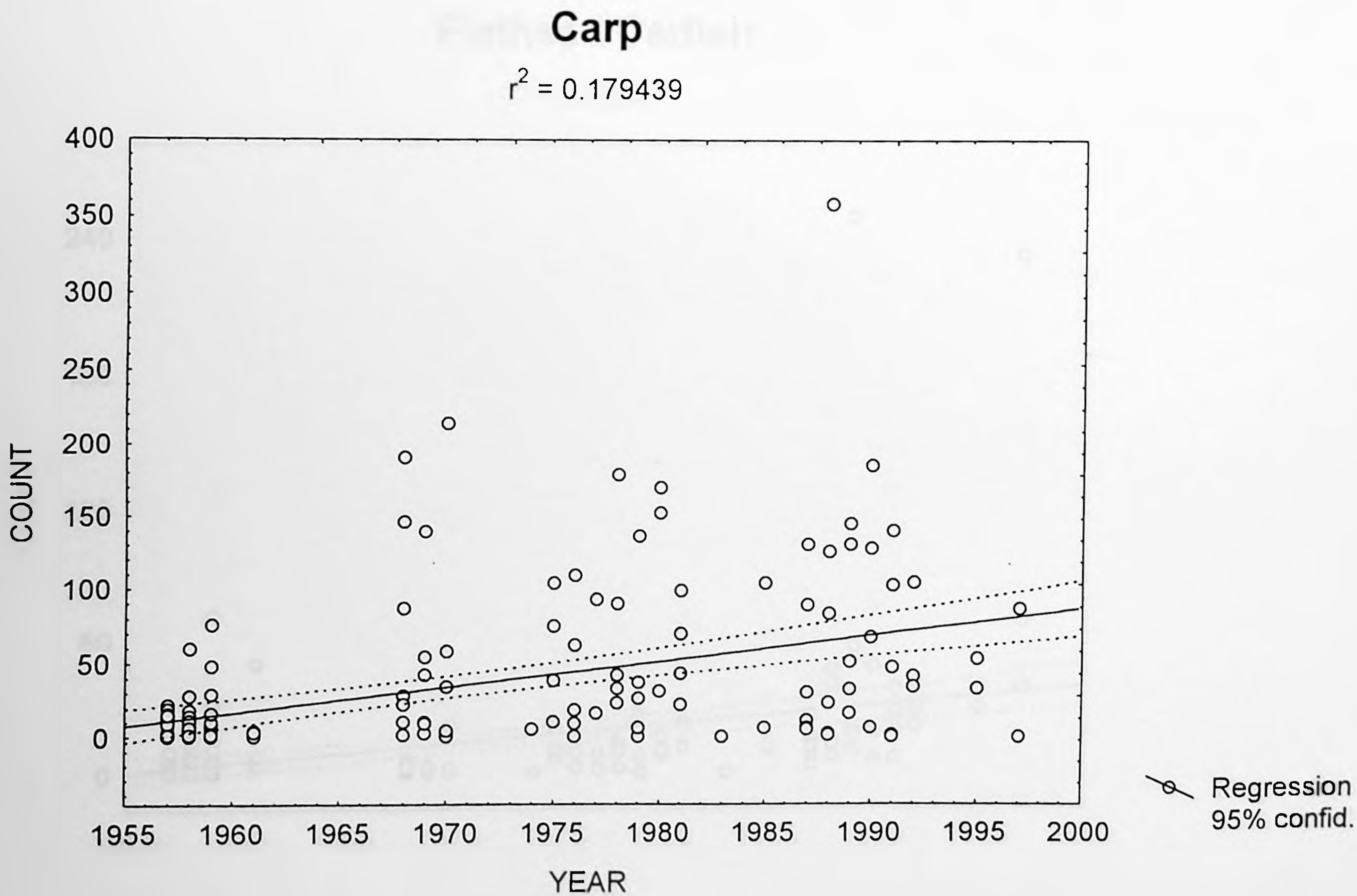

Fig. 45. Species showing a positive temporal/density correlation along the middle river section.

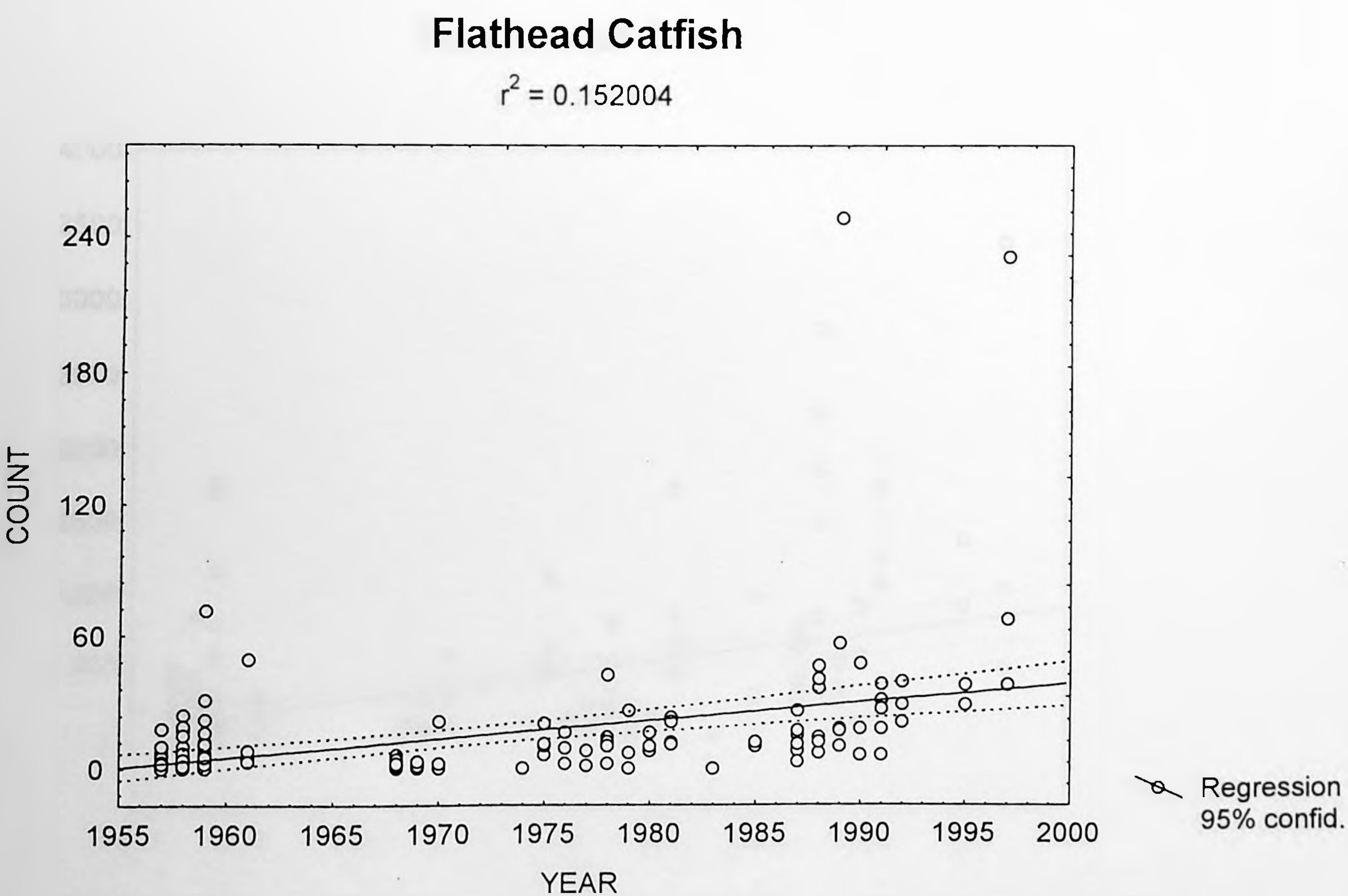

Fig. 46. Species showing a positive temporal/density correlation along the middle river section.

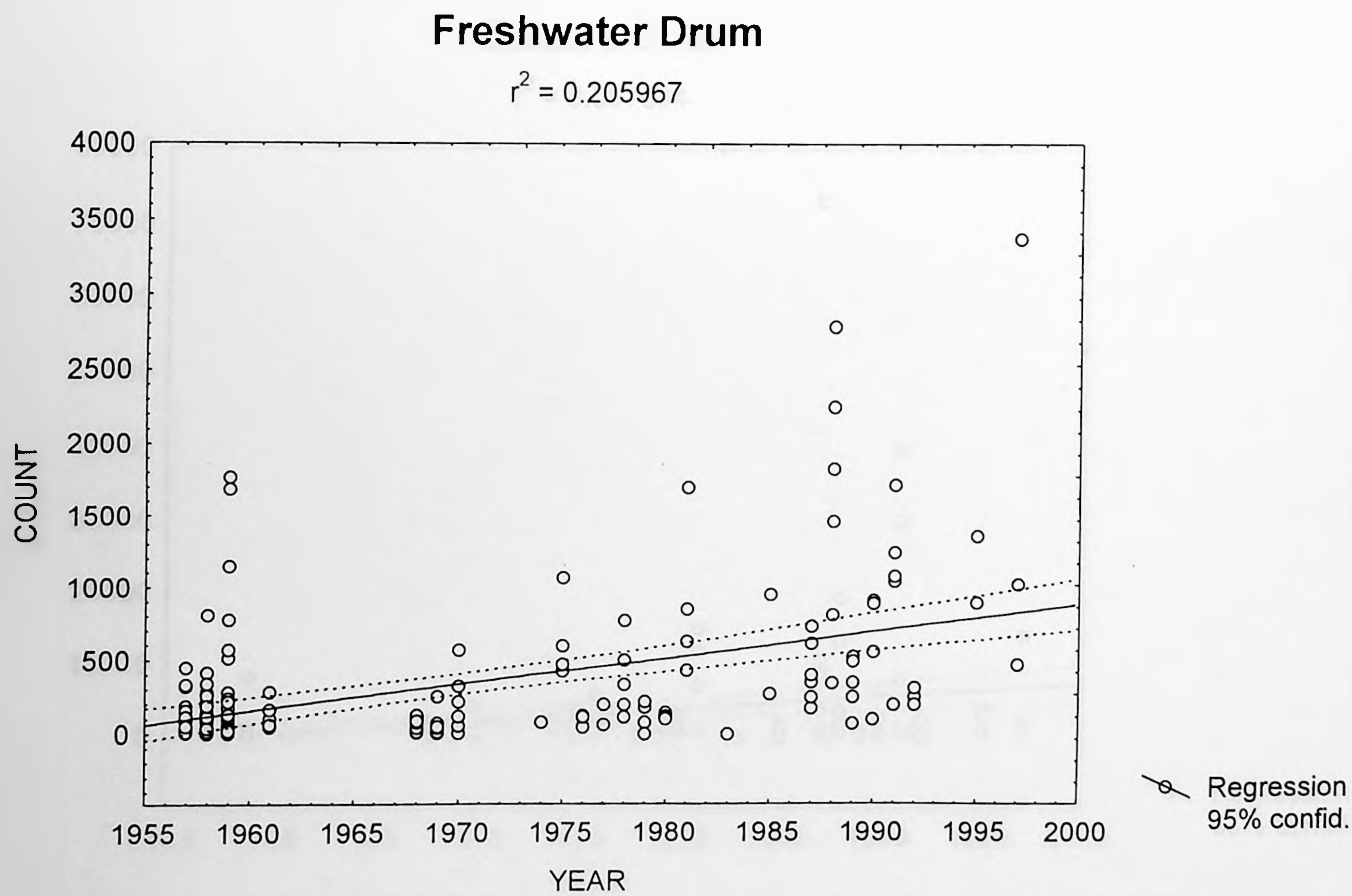

Fig. 47. Species showing a positive temporal/density correlation along the middle river section.

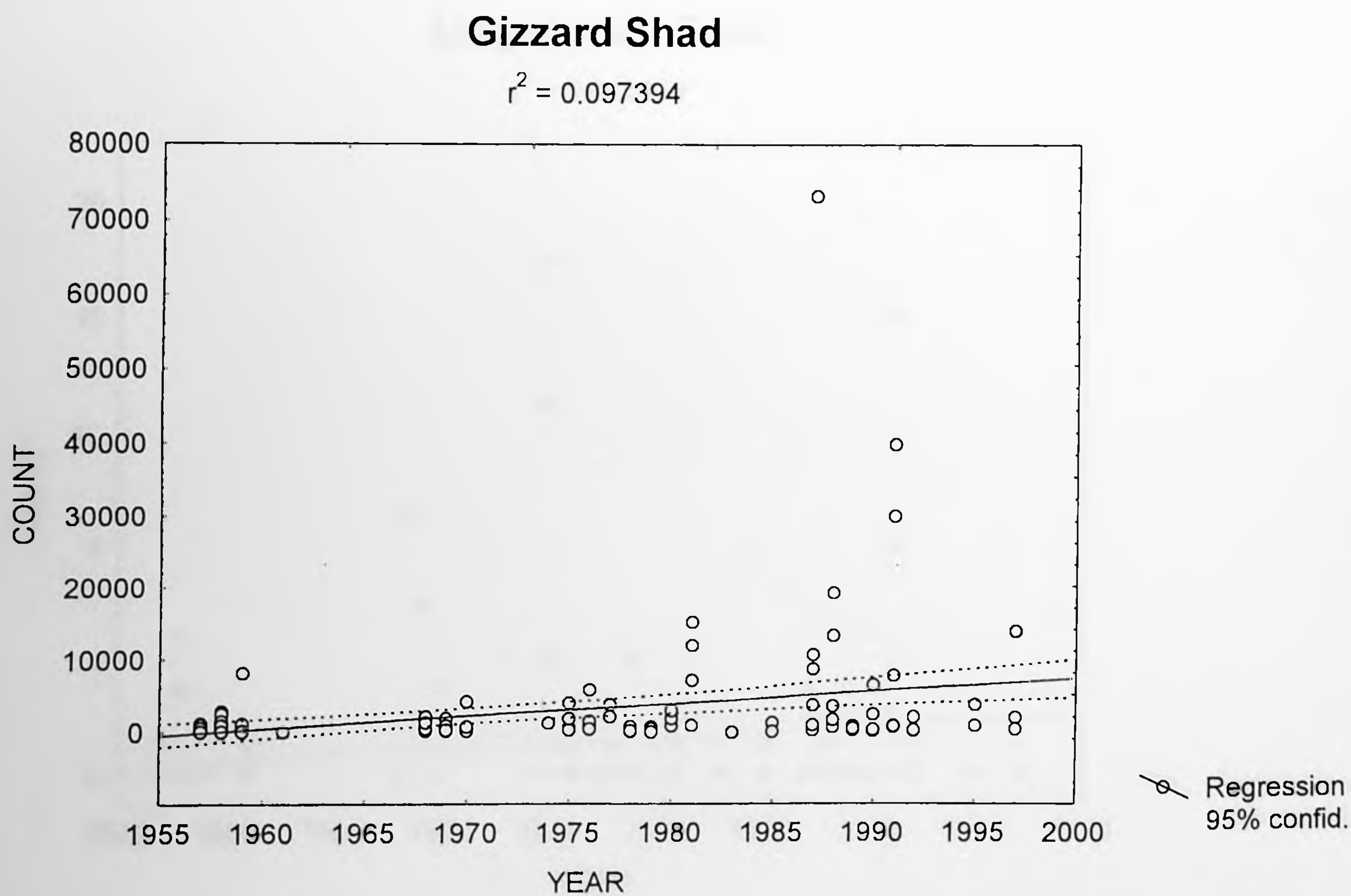

Fig. 48. Species showing a positive temporal/density correlation along the middle river section.

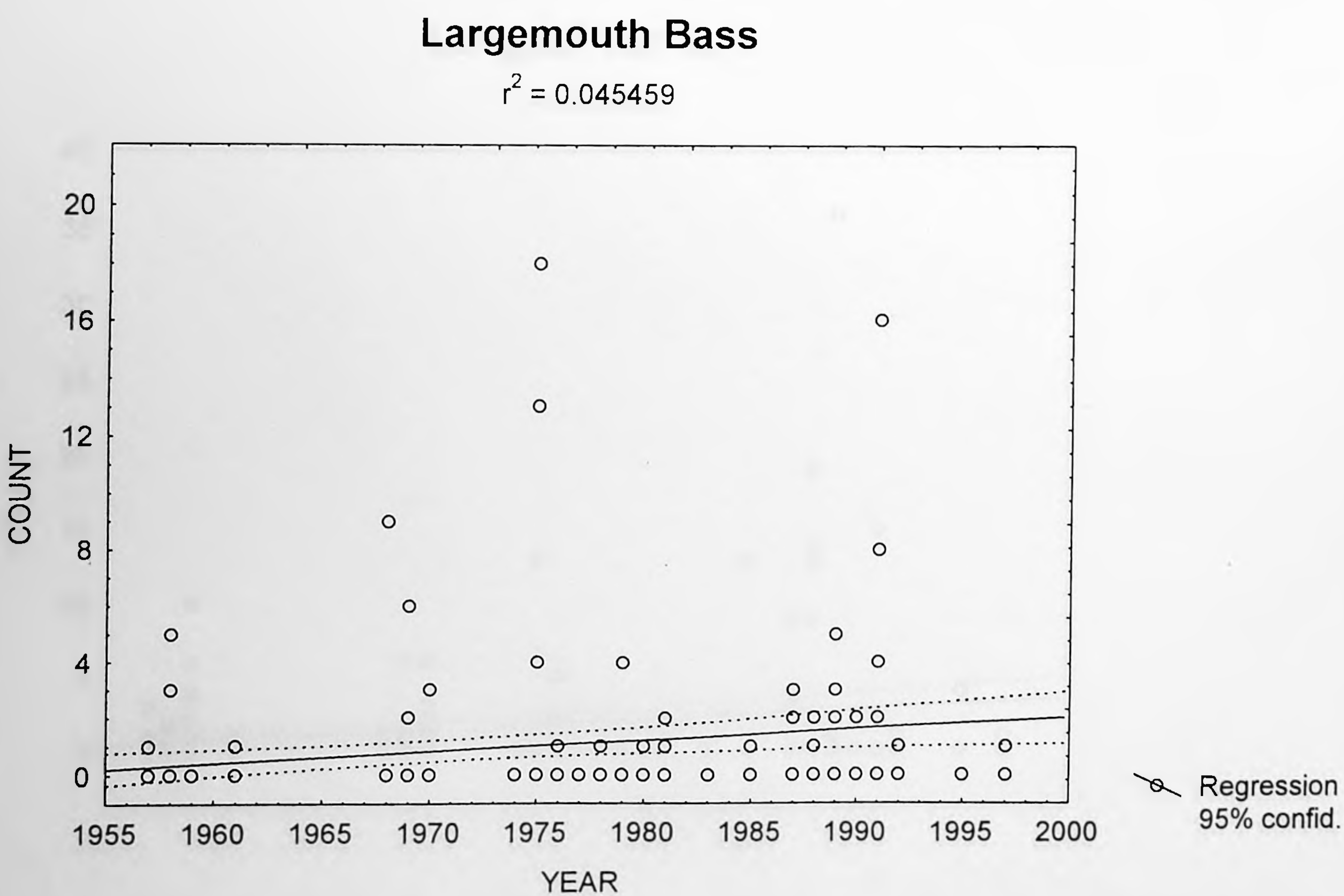

Fig. 49. Species showing a positive temporal/density correlation along the middle river section.

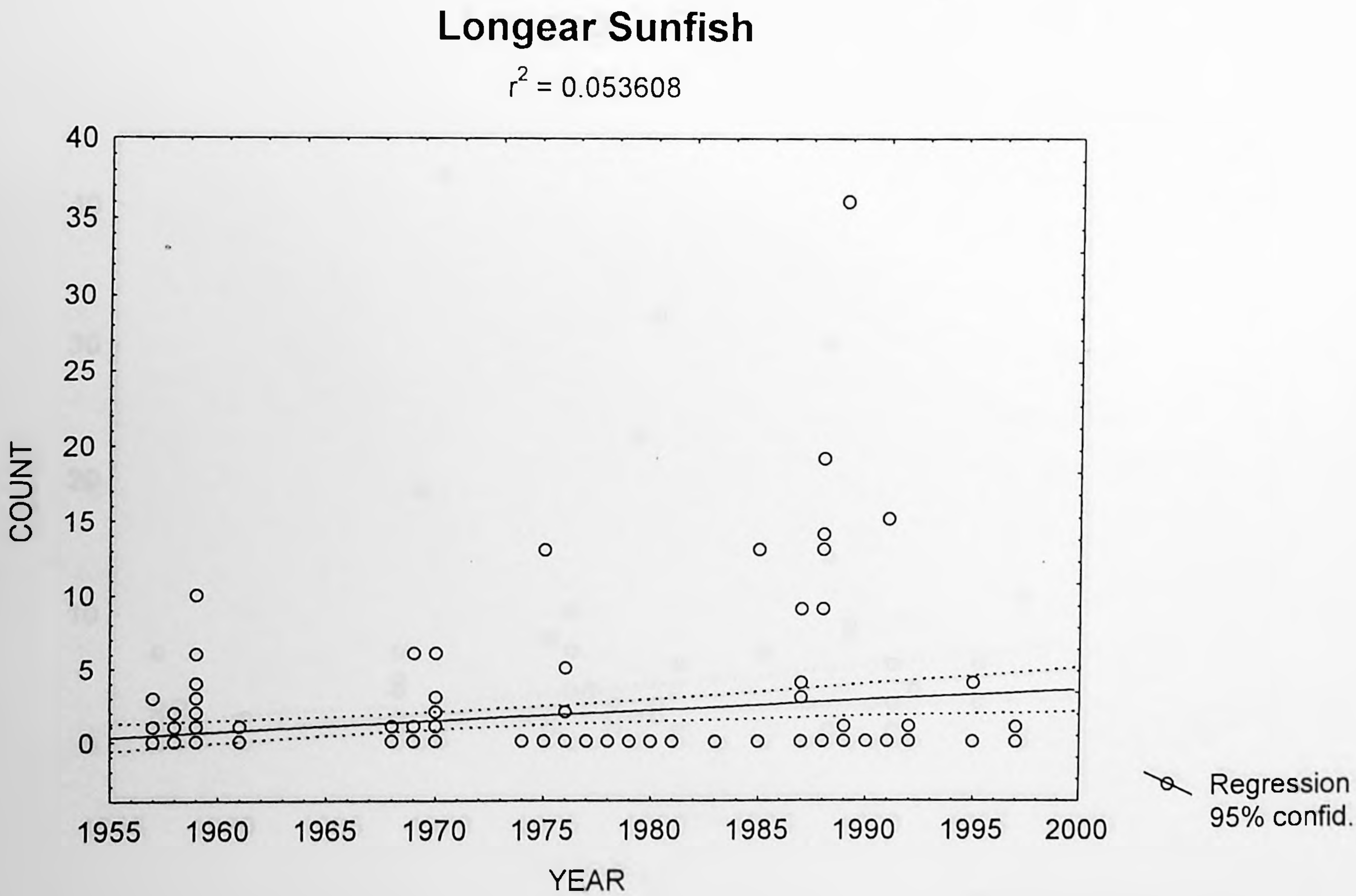

Fig. 50. Species showing a positive temporal/density correlation along the middle river section.

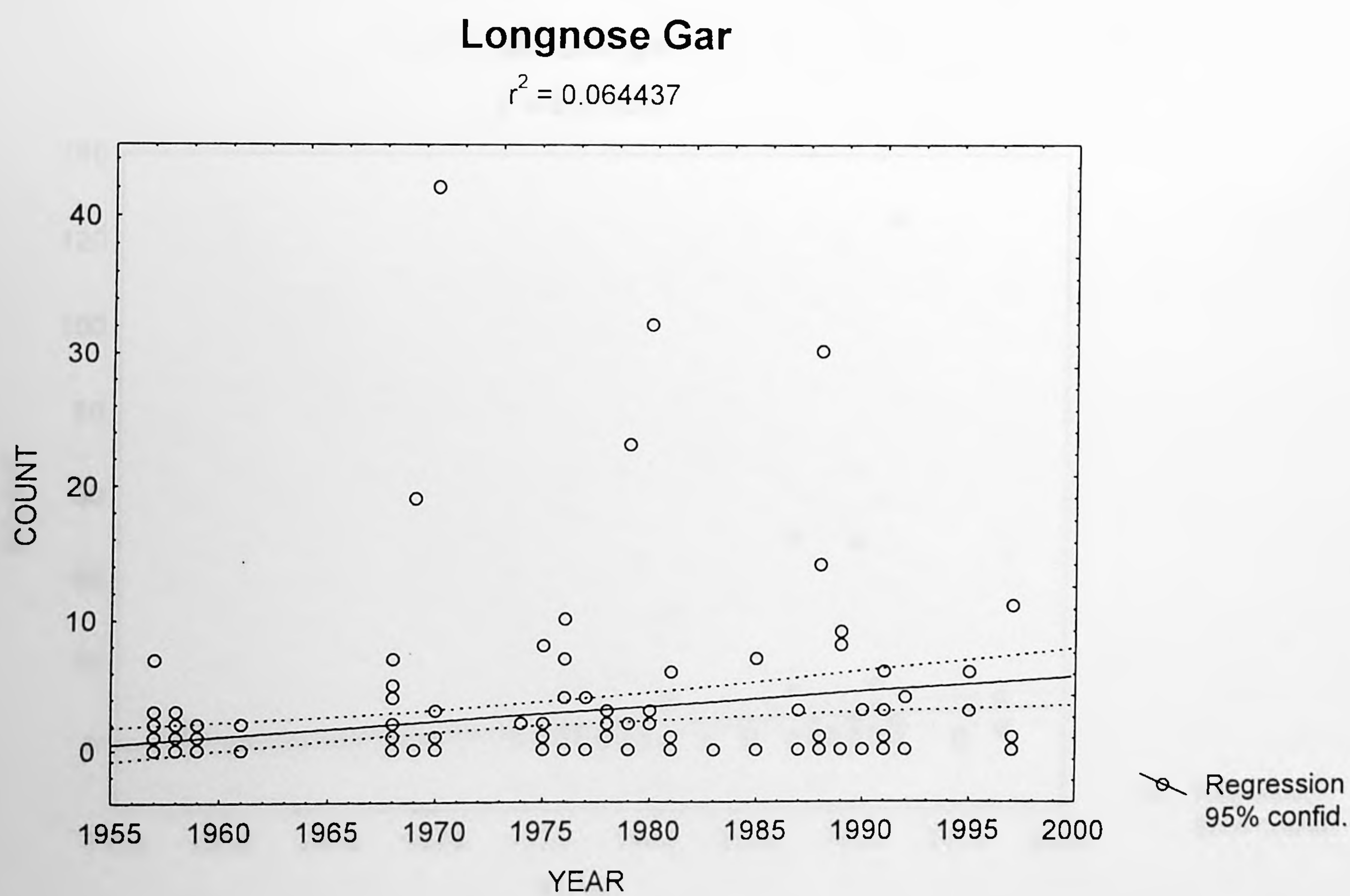

Fig. 51. Species showing a positive temporal/density correlation along the middle river section.

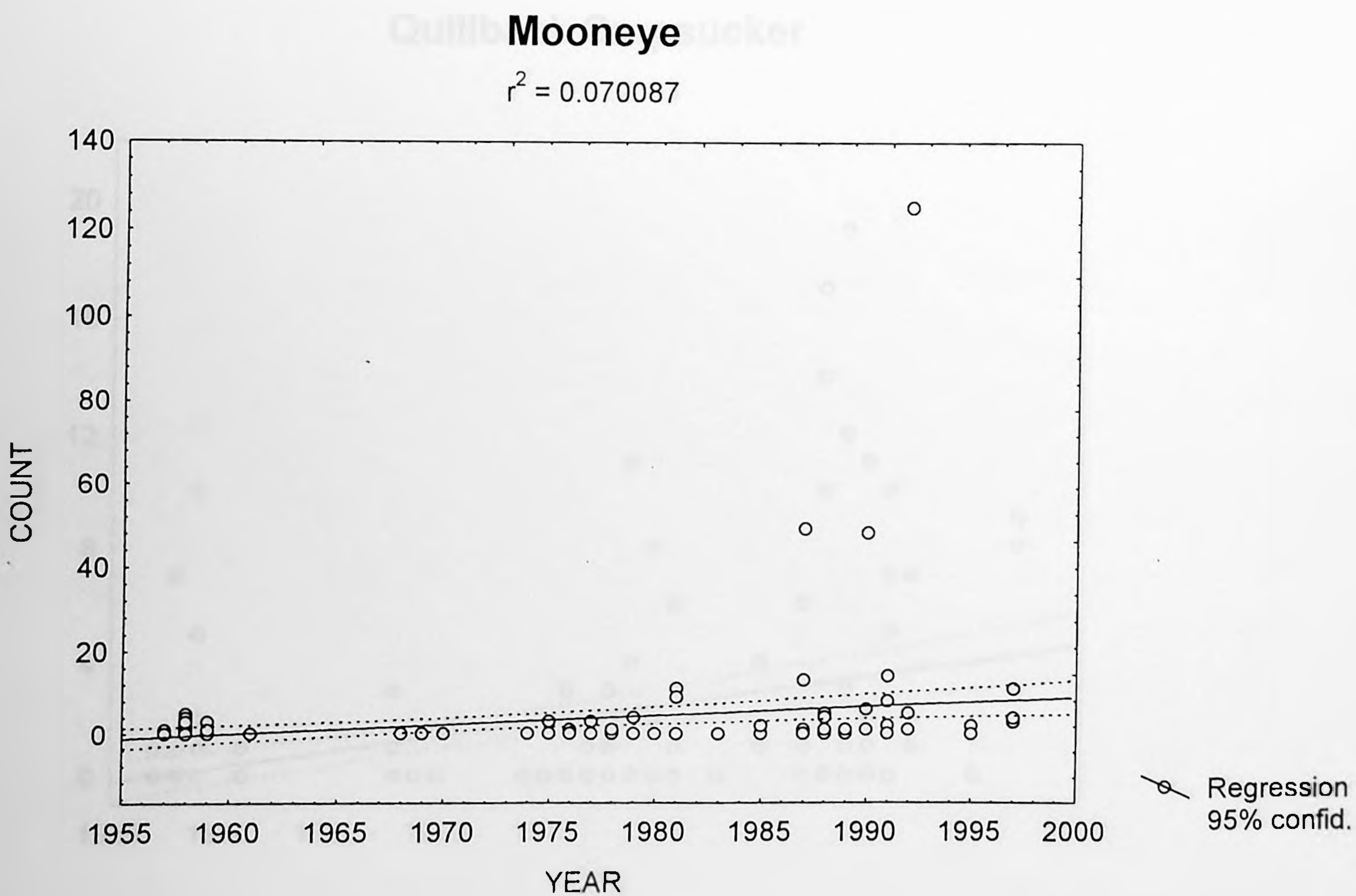

Fig. 52. Species showing a positive temporal/density correlation along the middle river section.

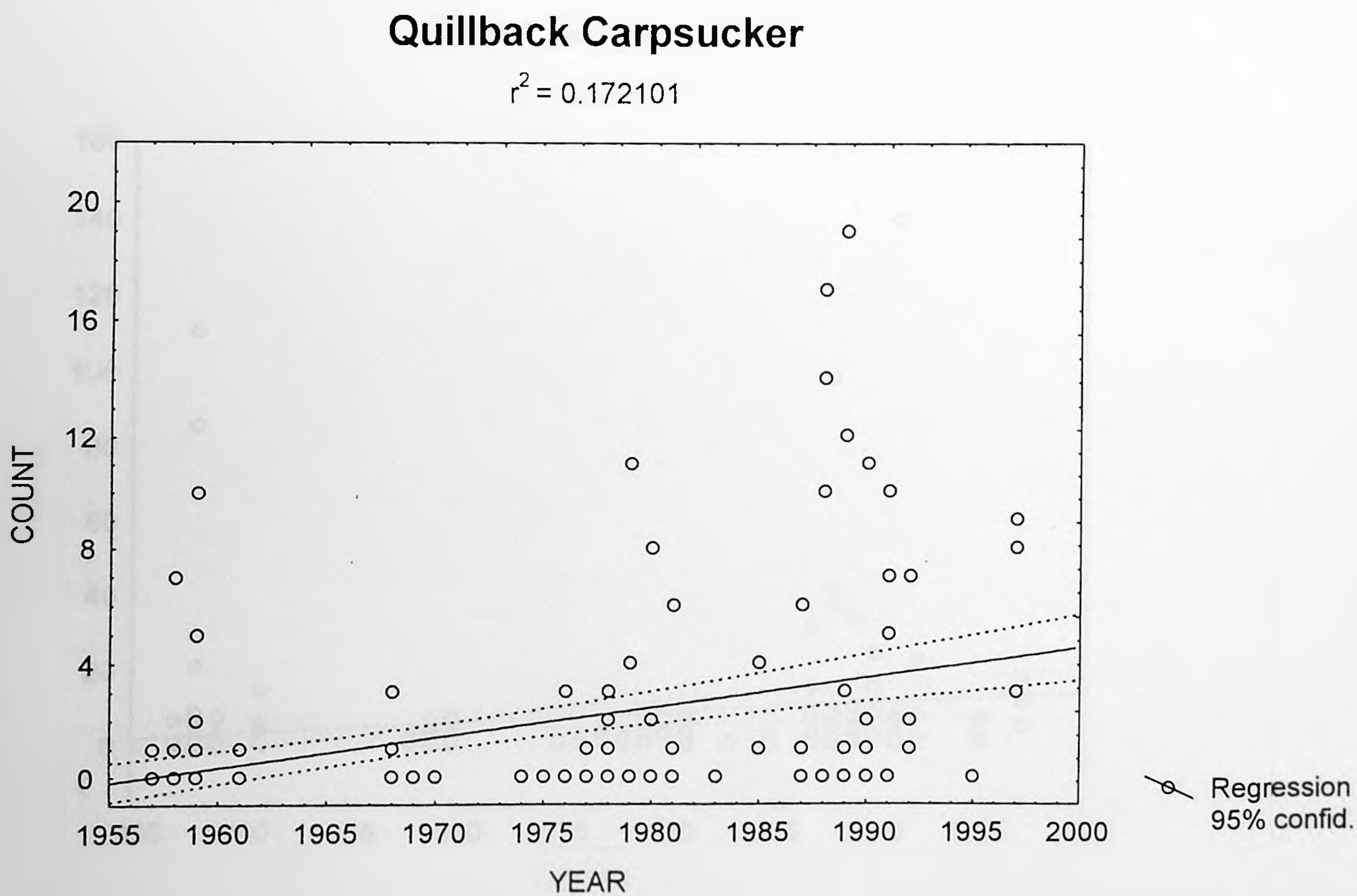

Fig. 53. Species showing a positive temporal/density correlation along the middle river section.

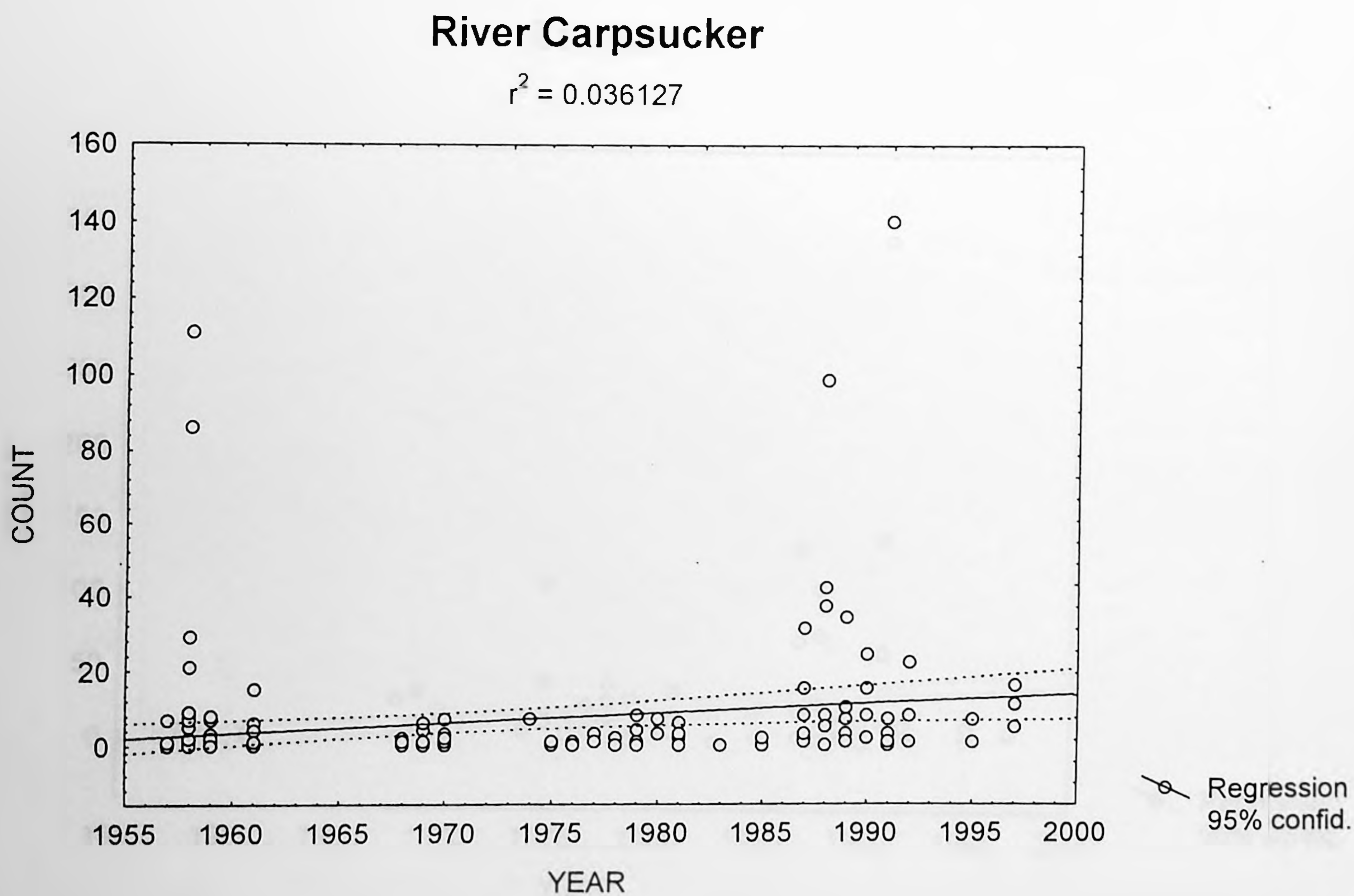

Fig. 54. Species showing a positive temporal/density correlation along the middle river section.

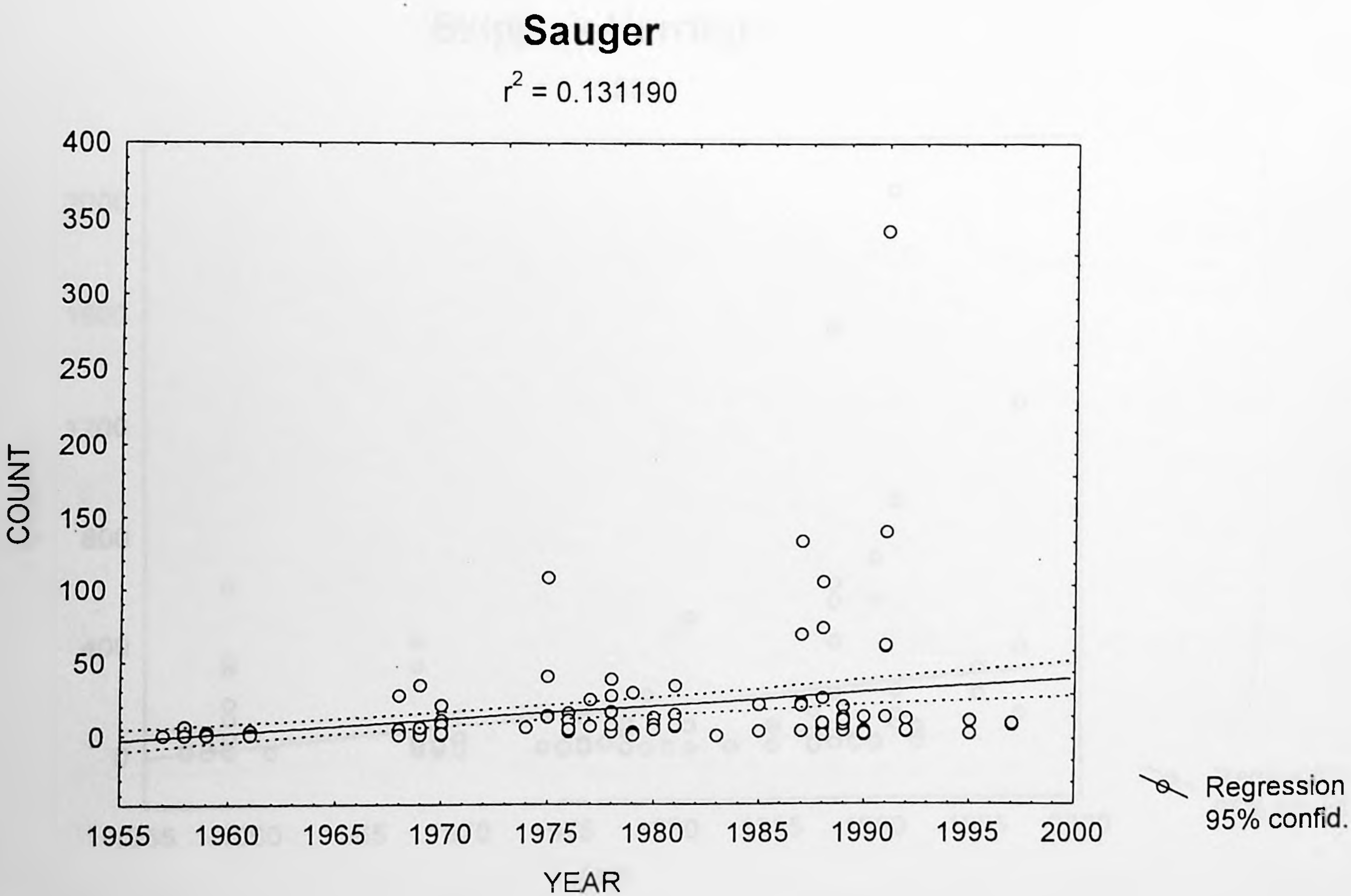

Fig. 55. Species showing a positive temporal/density correlation along the middle river section.

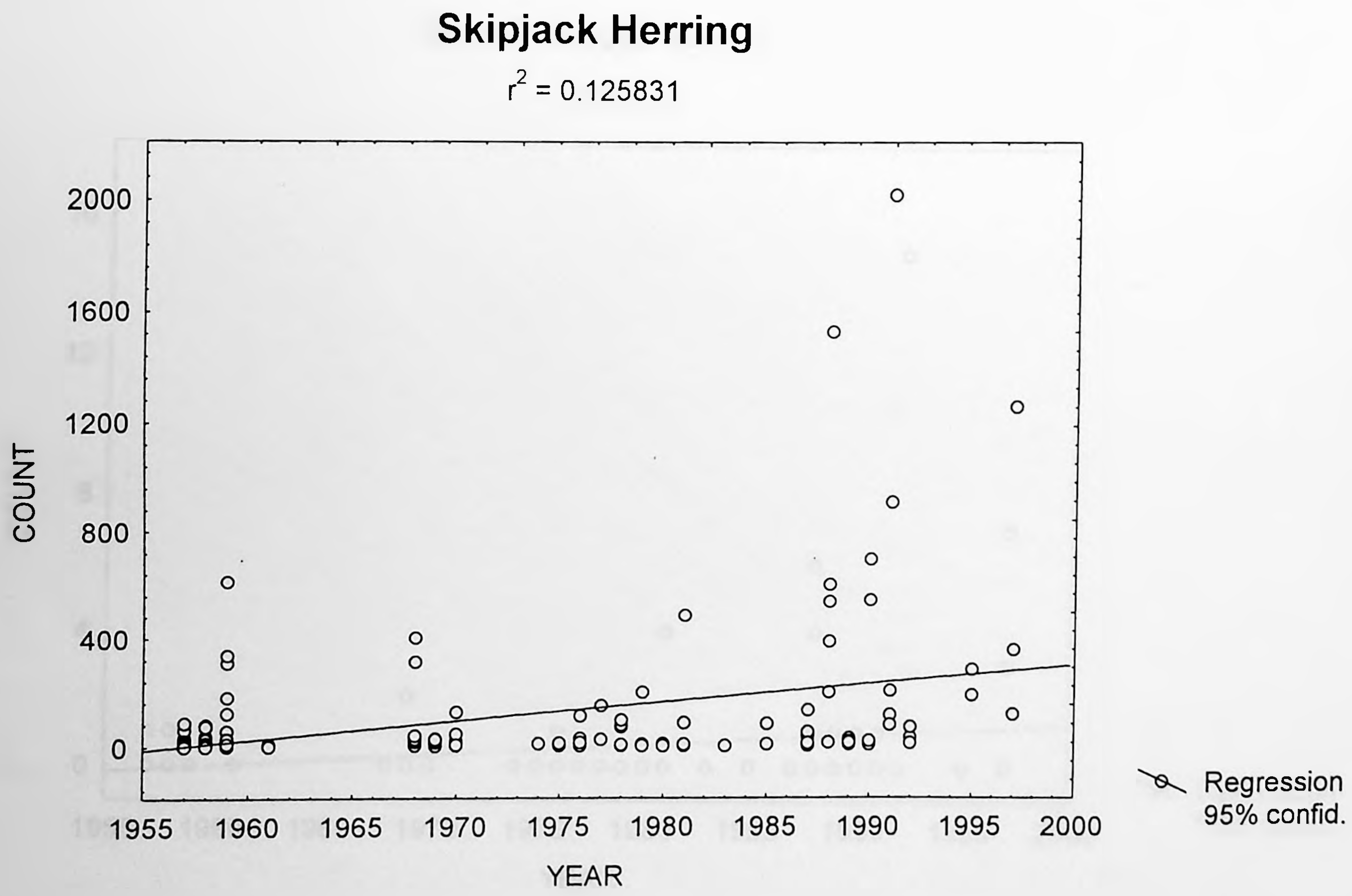

Fig. 56. Species showing a positive temporal/density correlation along the middle river section.

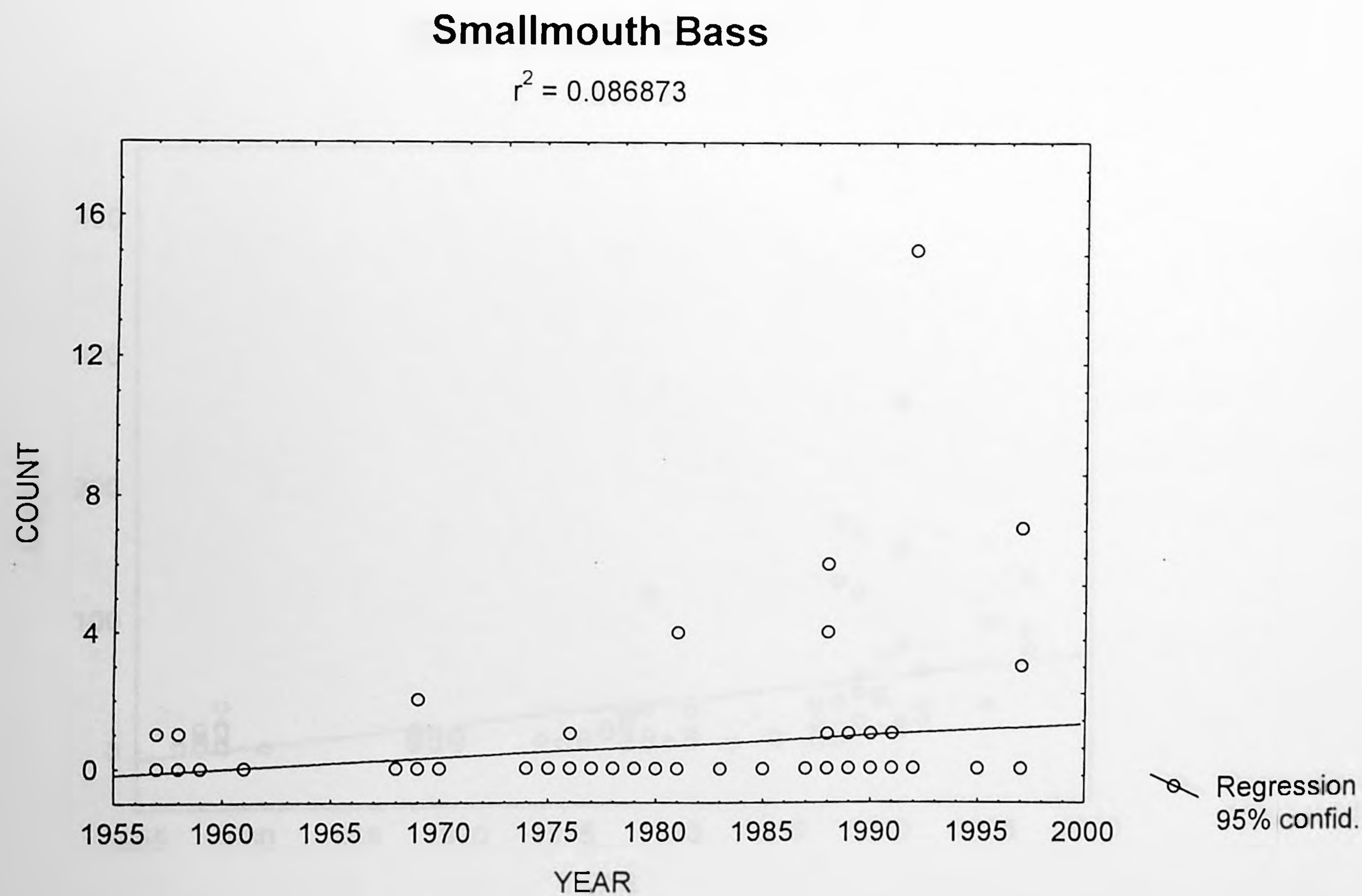

Fig. 57. Species showing a positive temporal/density correlation along the middle river section.

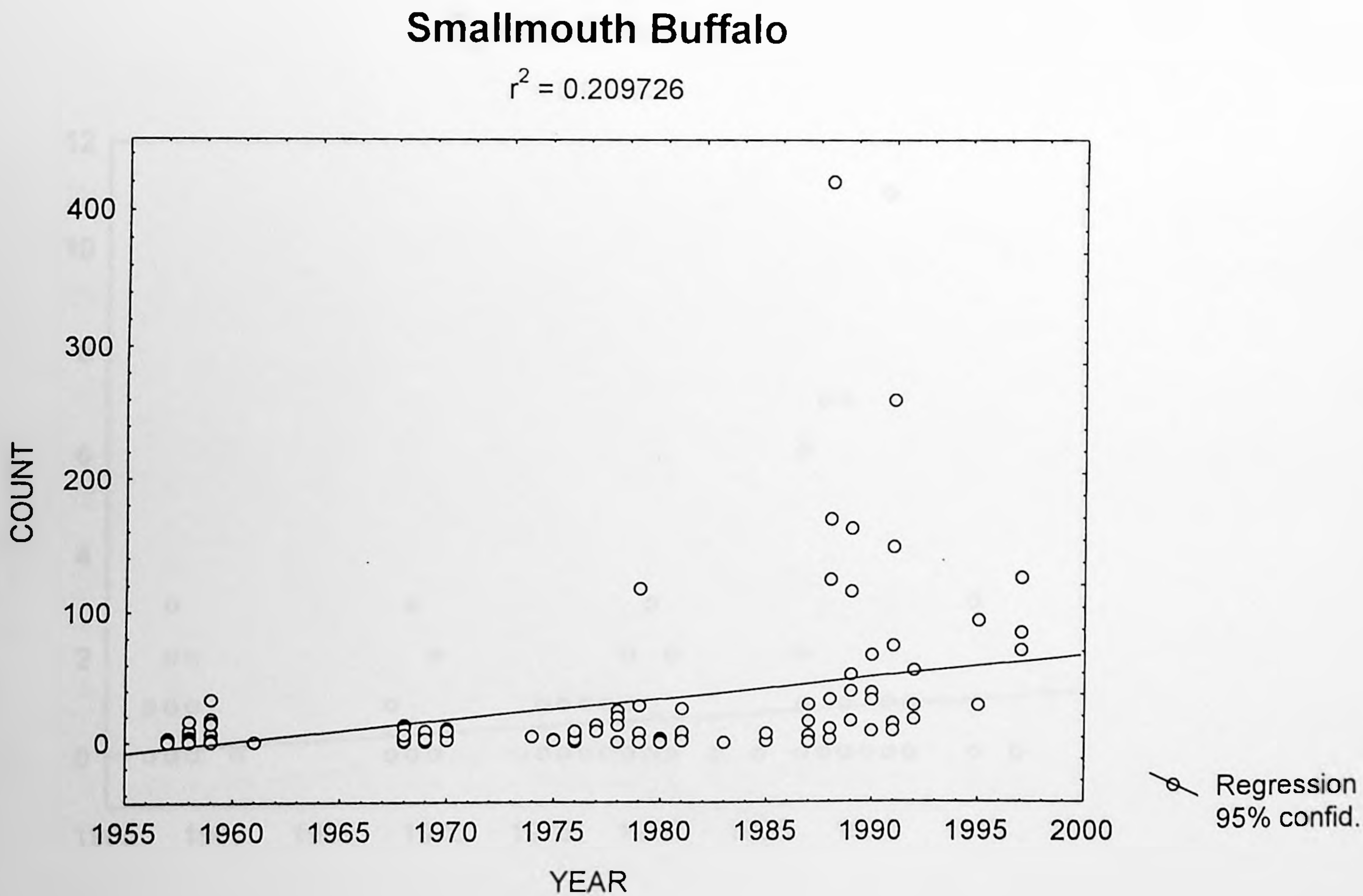

Fig. 58. Species showing a positive temporal/density correlation along the middle river section.

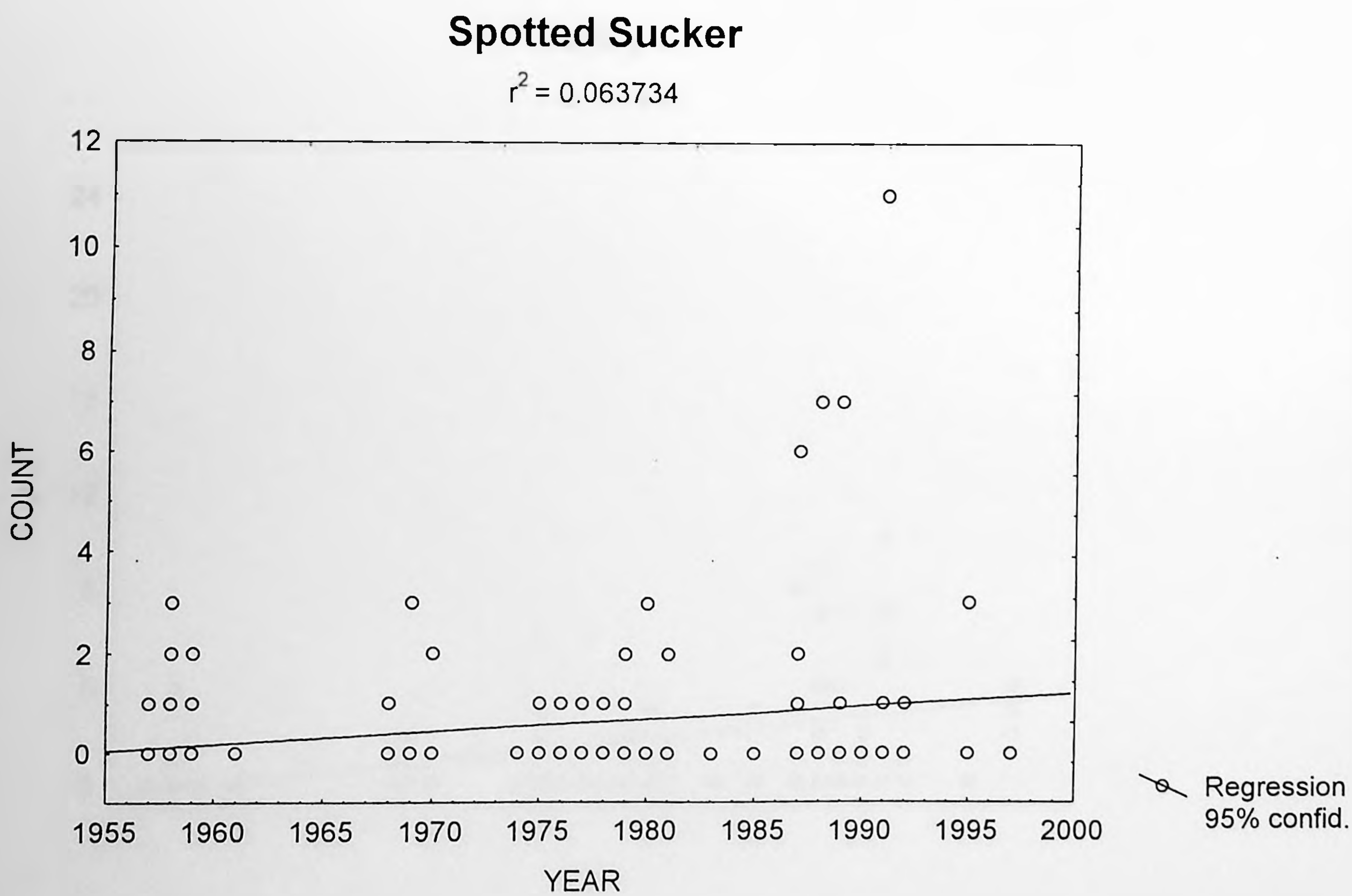

Fig. 59. Species showing a positive temporal/density correlation along the middle river section.

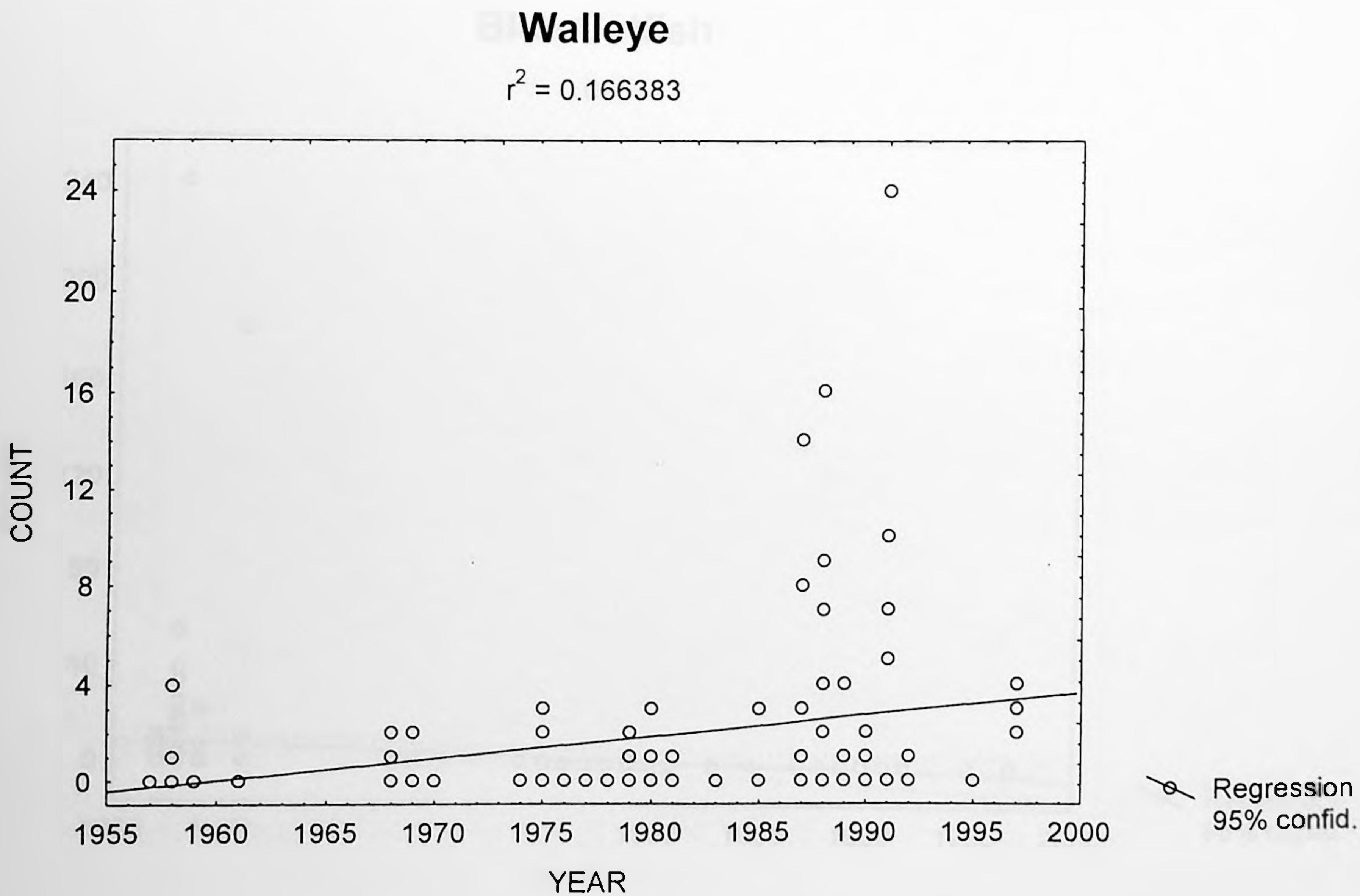

Fig. 60. Species showing a positive temporal/density correlation along the middle river section.

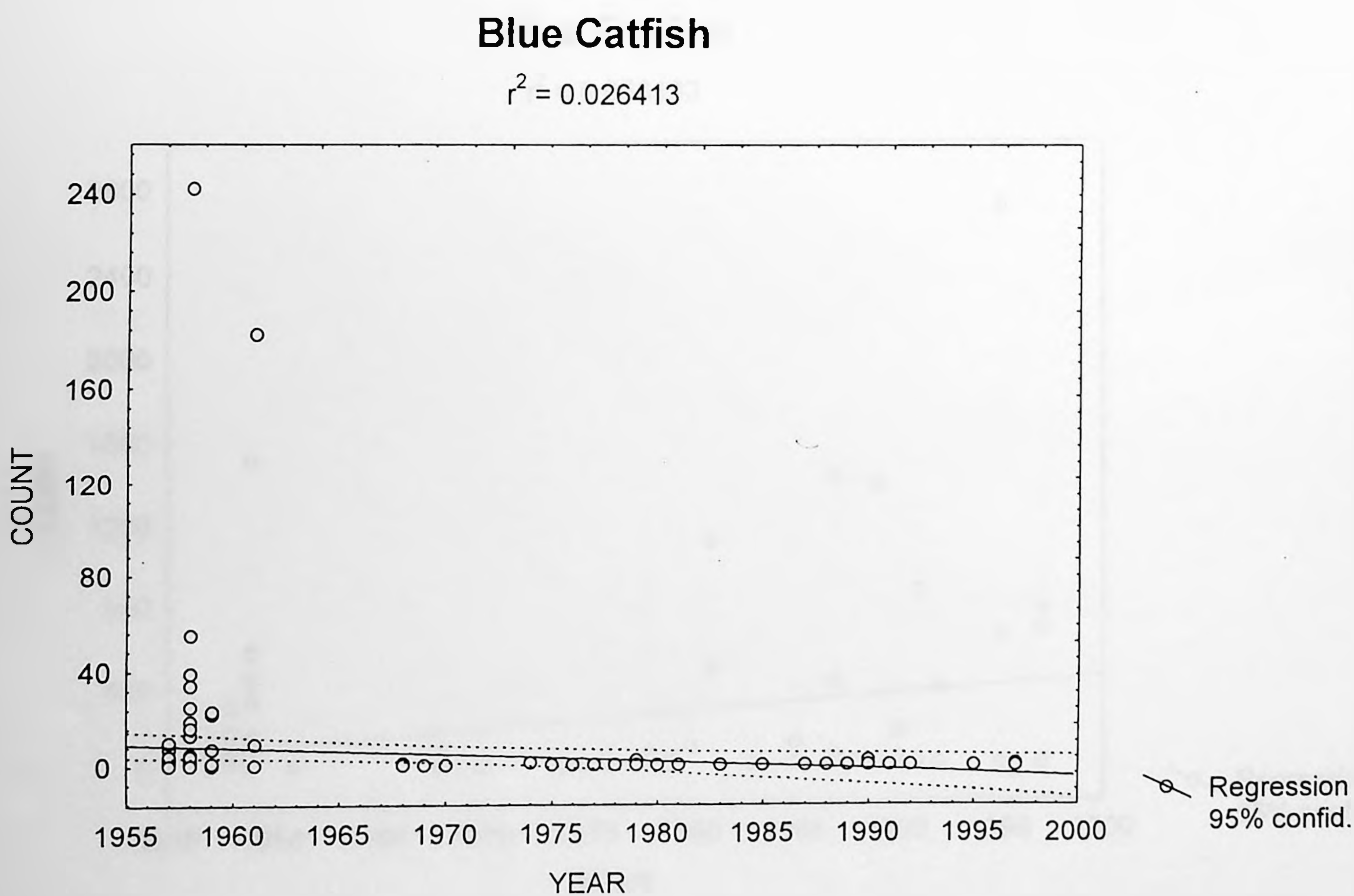

Fig. 61. Species showing a negative temporal/density correlation along the middle river section.

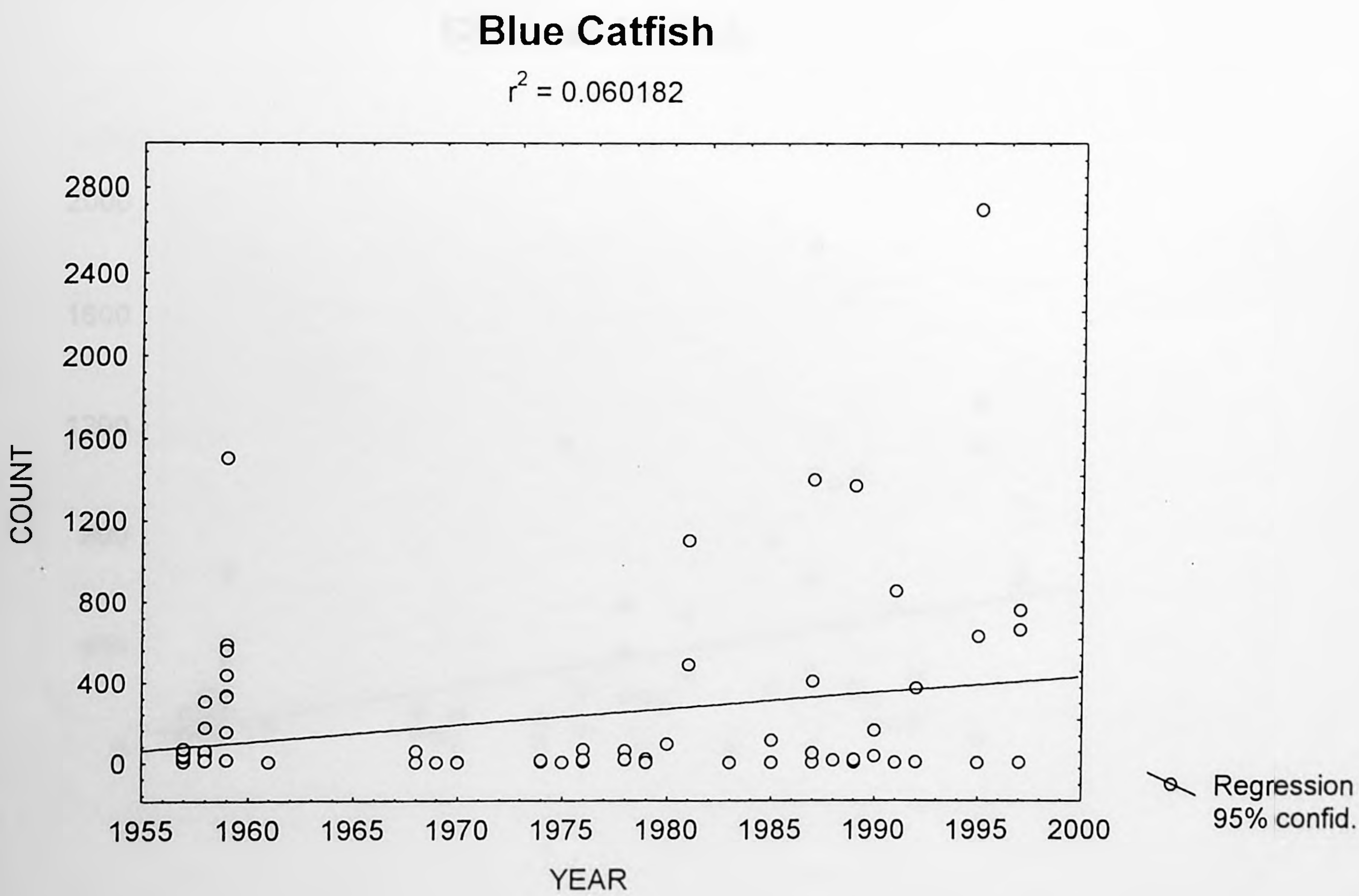

Fig. 62. Species showing a positive temporal/density correlation along the lower river section.

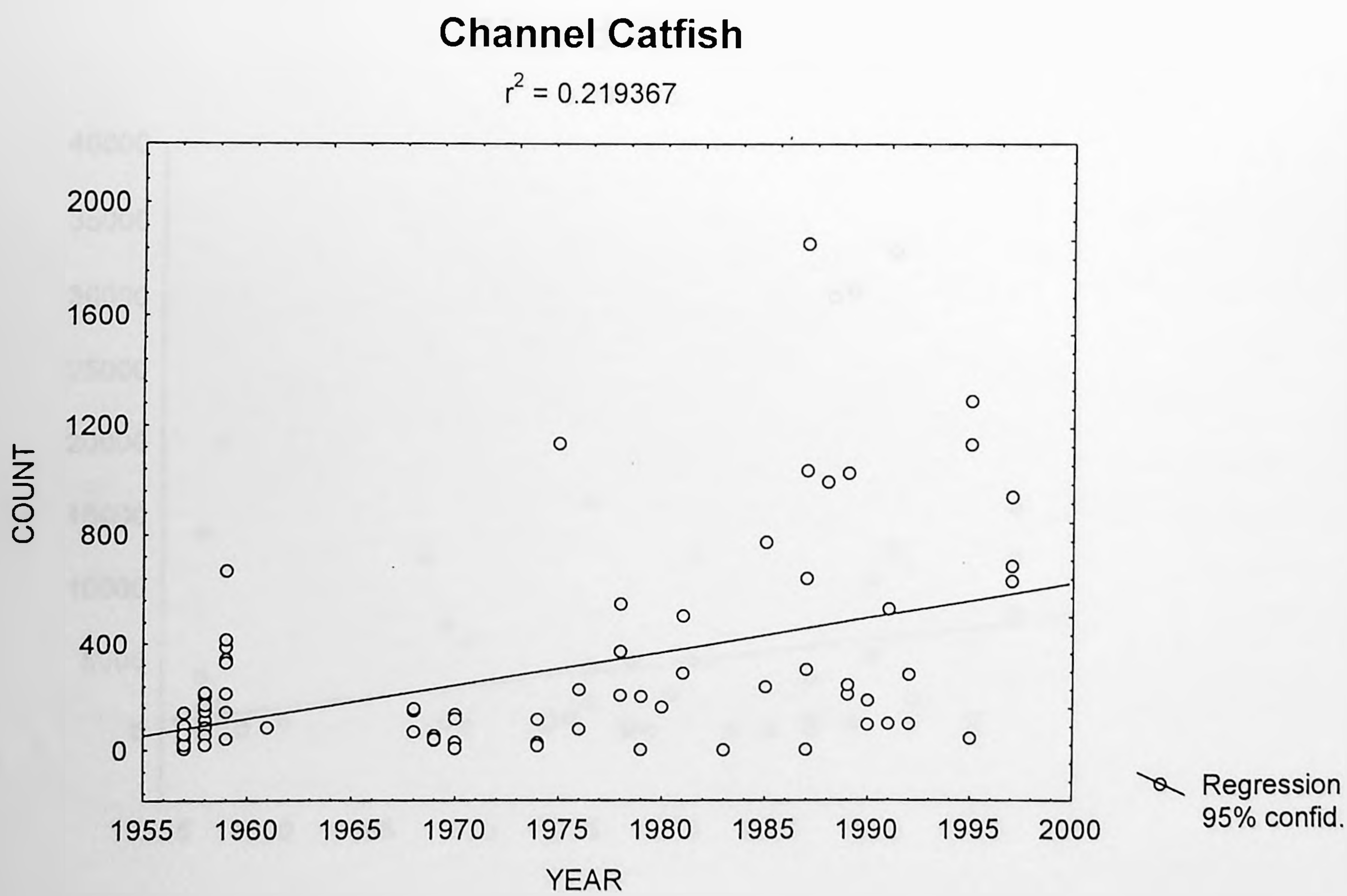

Fig. 63. Species showing a positive temporal/density correlation along the lower river section.

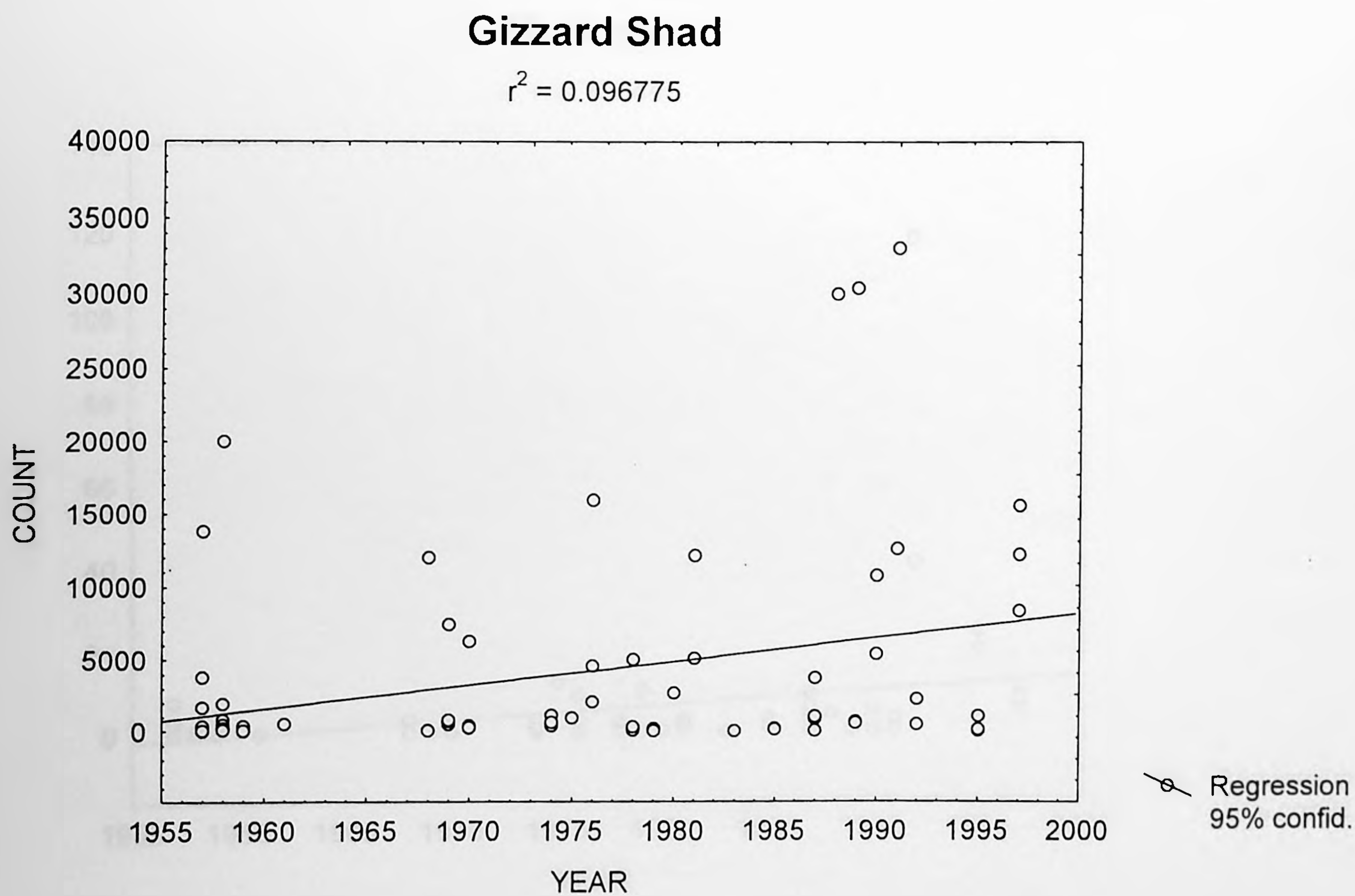

Fig. 64. Species showing a positive temporal/density correlation along the lower river section.

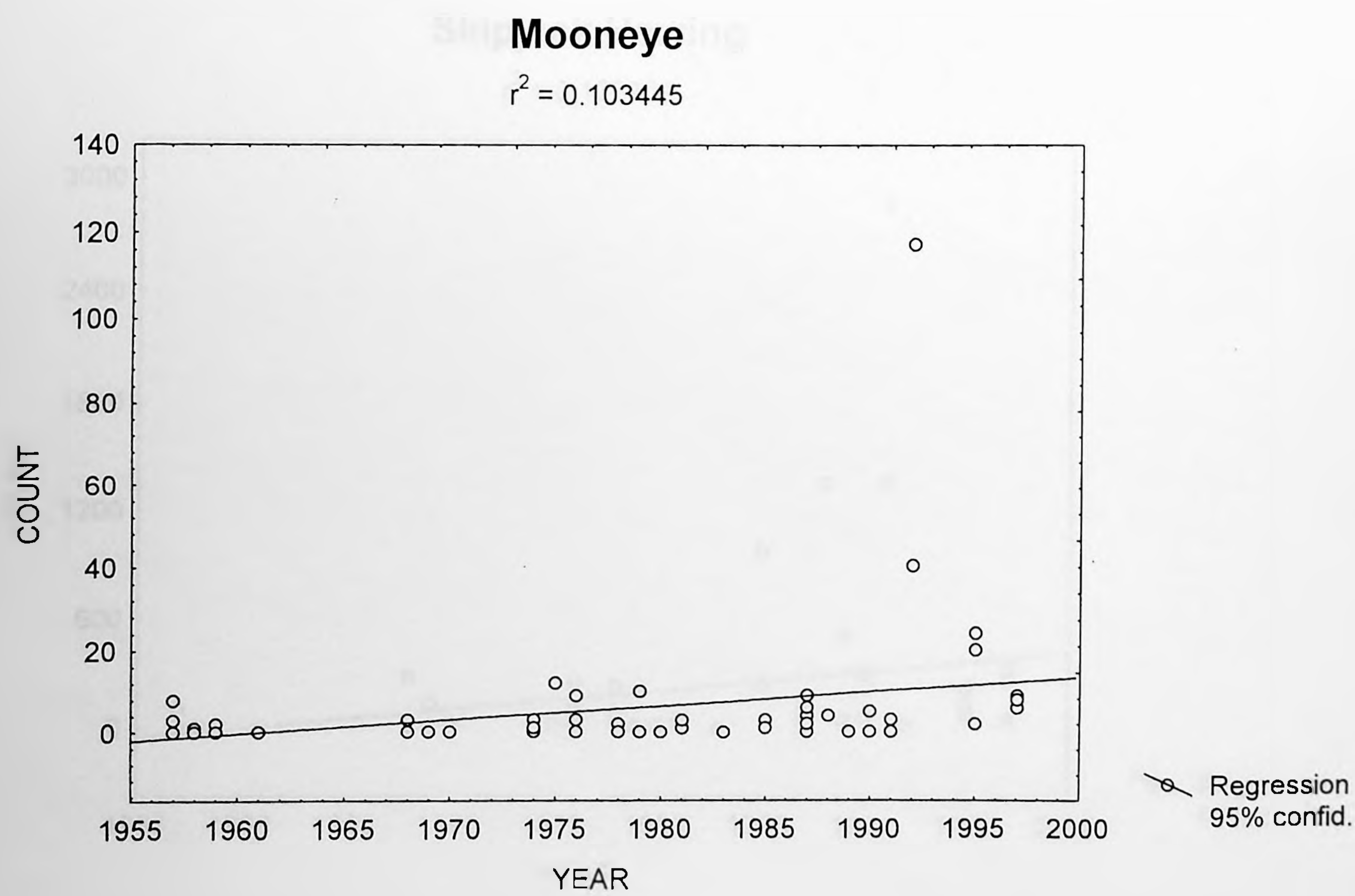

Fig. 65. Species showing a positive temporal/density correlation along the lower river section.

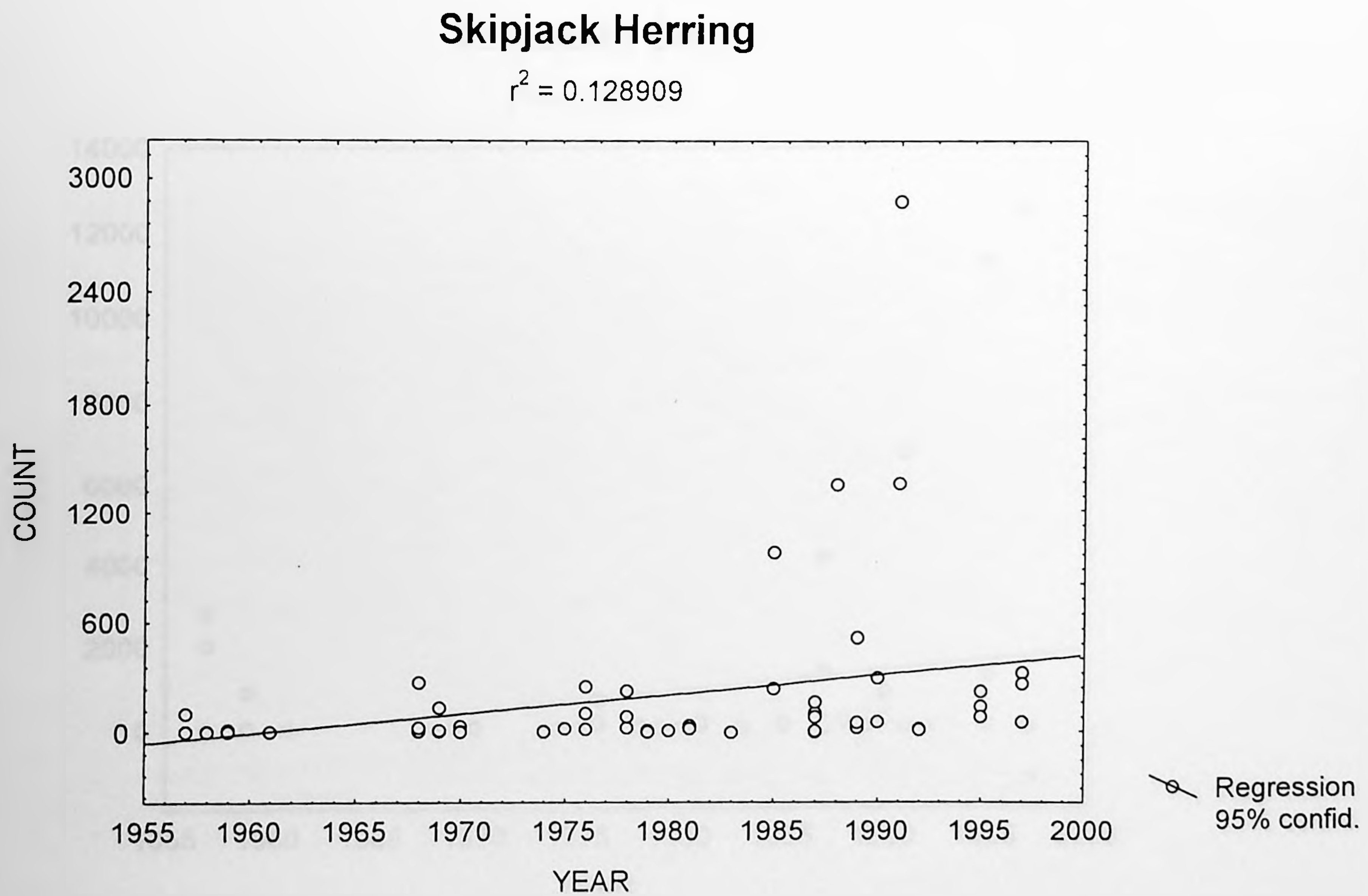

Fig. 66. Species showing a positive temporal/density correlation along the lower river section.

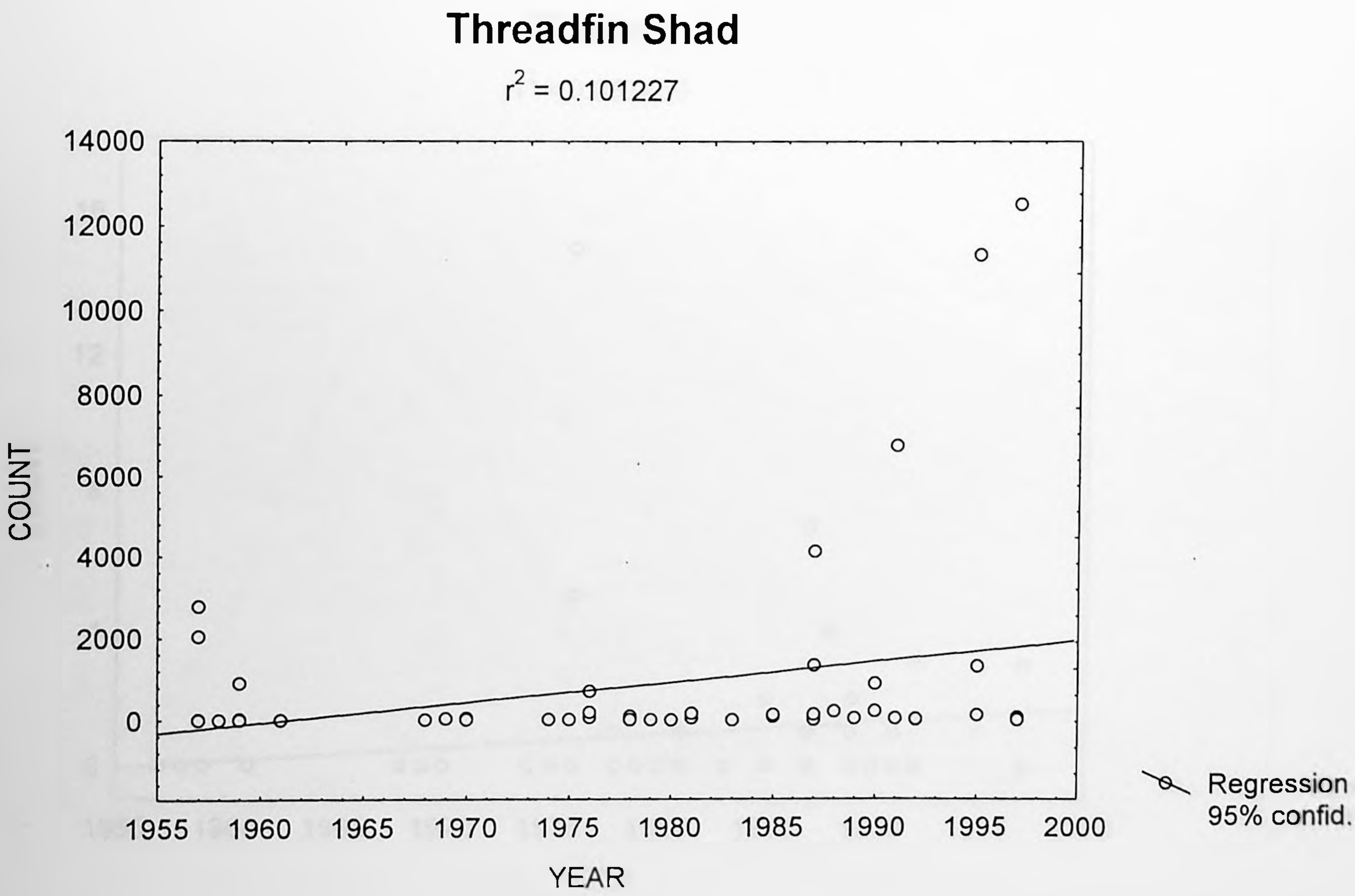

Fig. 67. Species showing a positive temporal/density correlation along the lower river section.

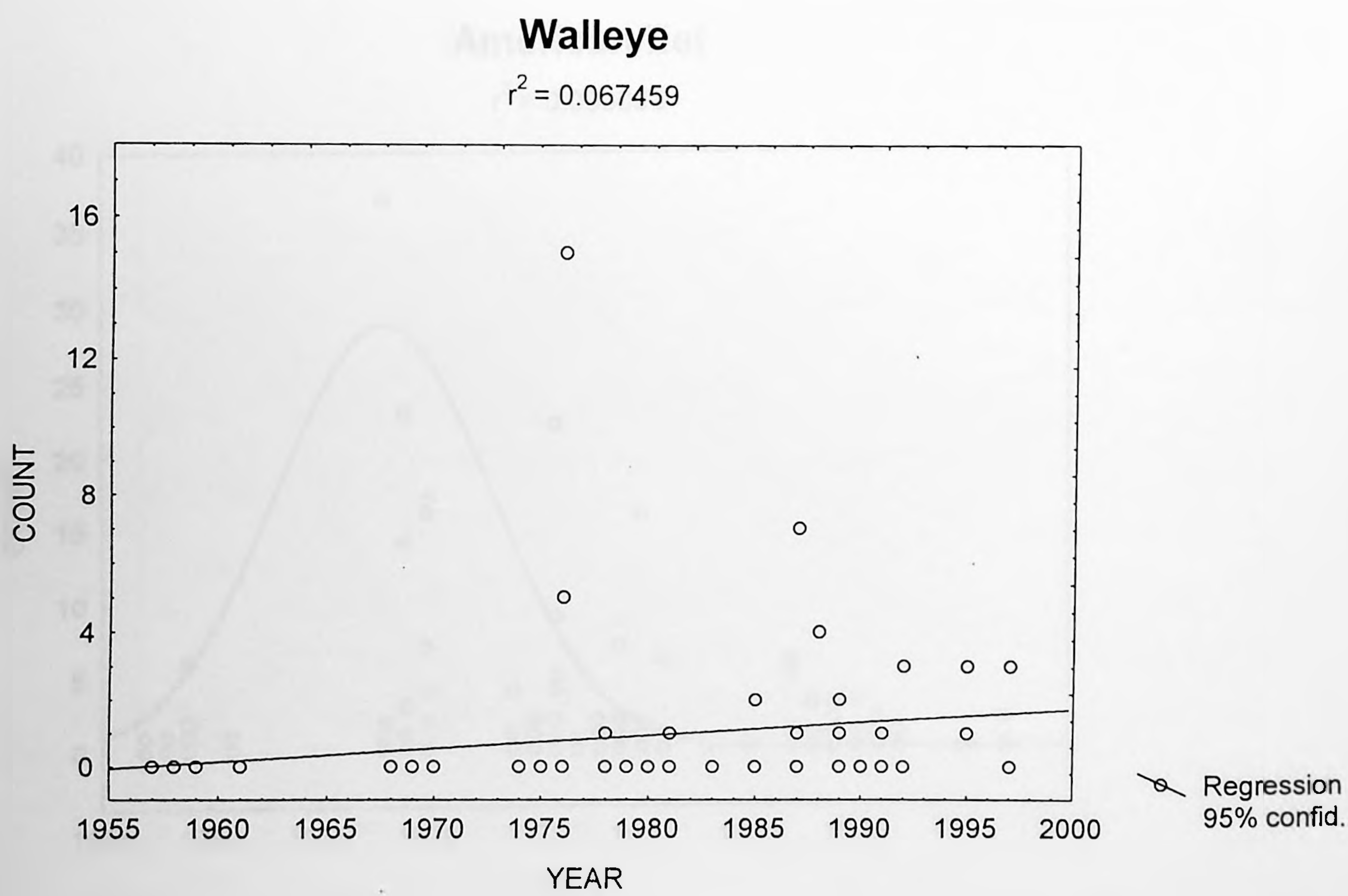

Fig. 68. Species showing a positive temporal/density correlation along the lower river section.

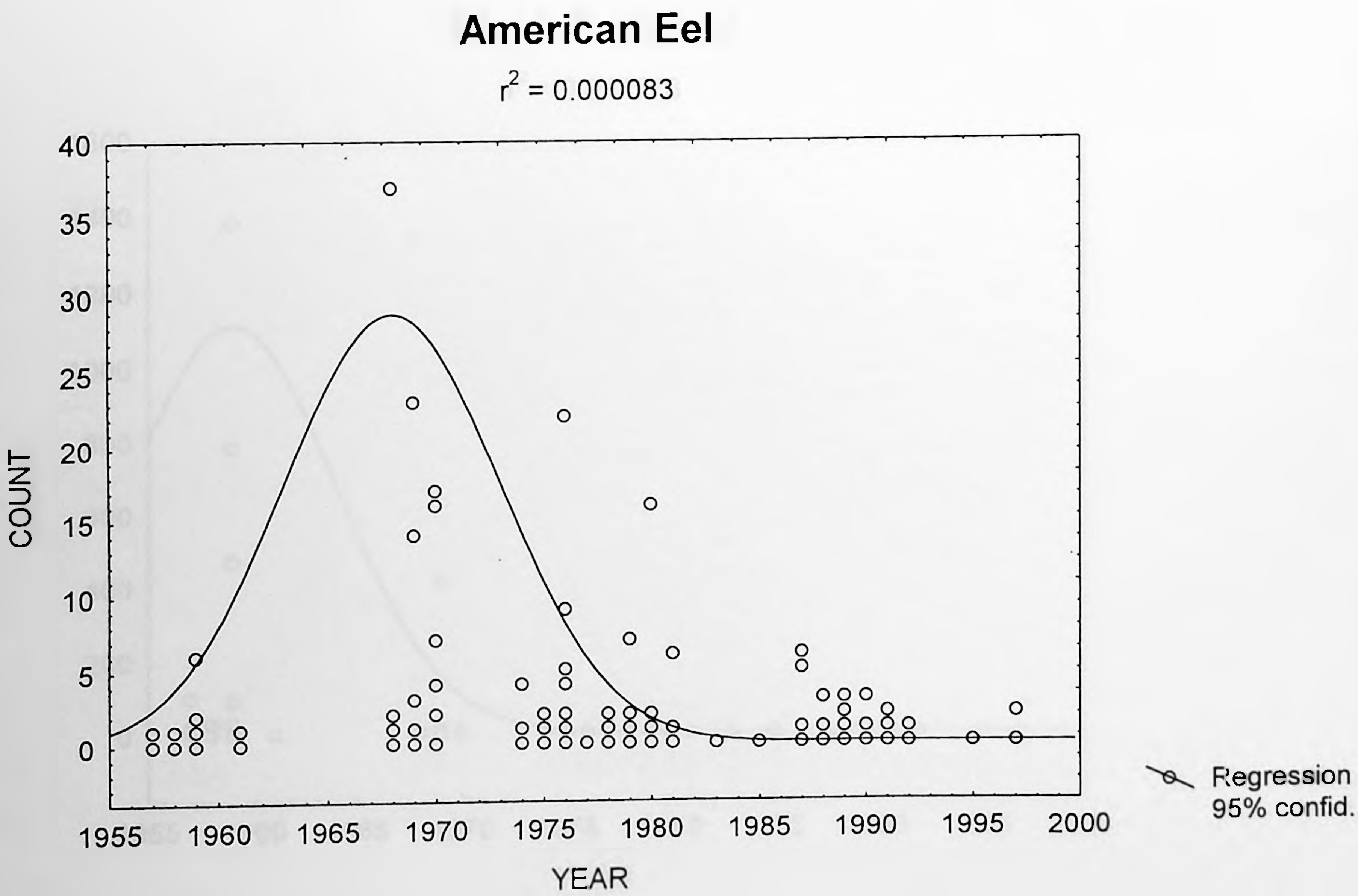

Fig. 69. Species showing a density peak along the entire river.

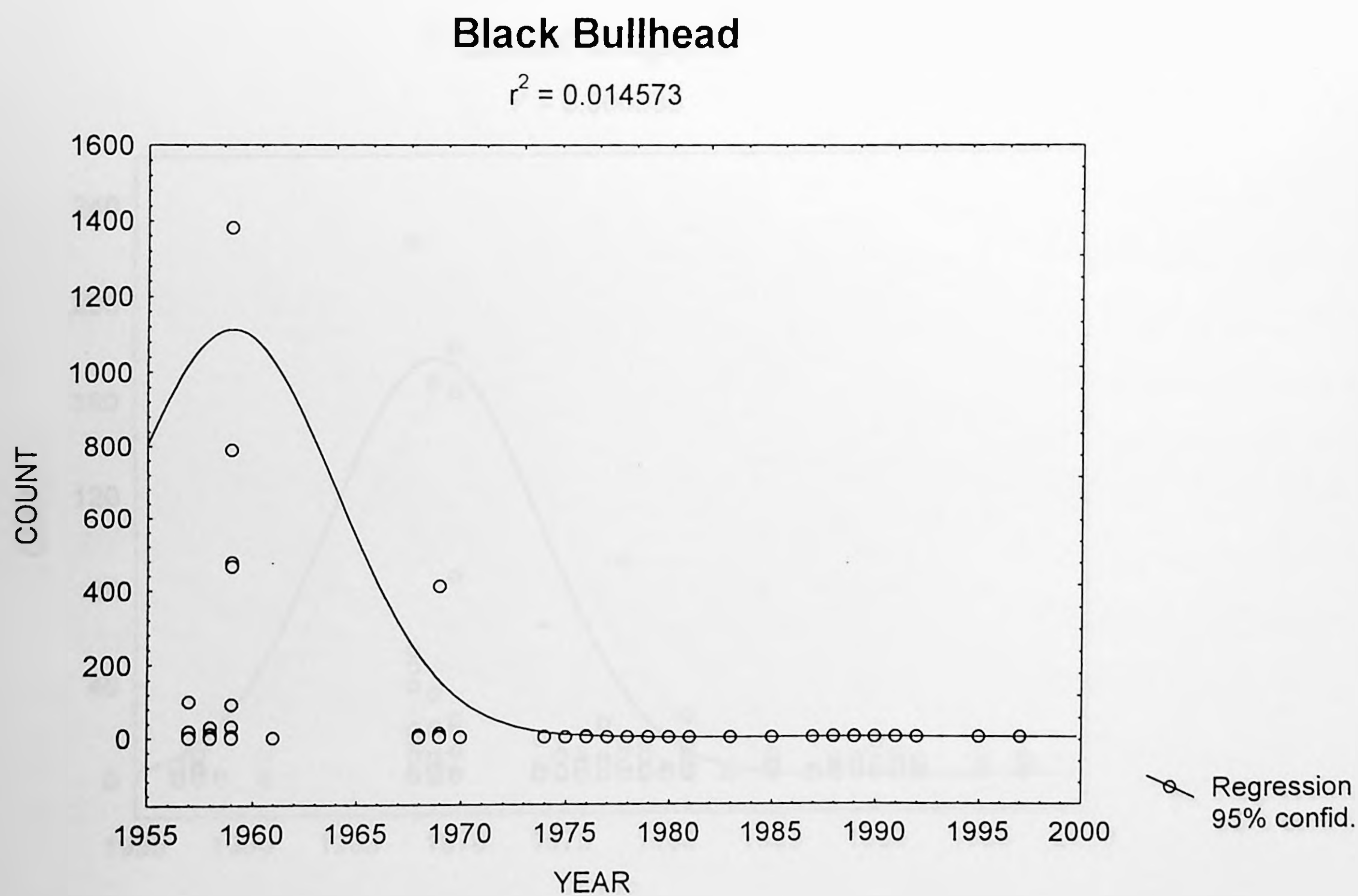

Fig. 70. Species showing a density peak along the entire river.

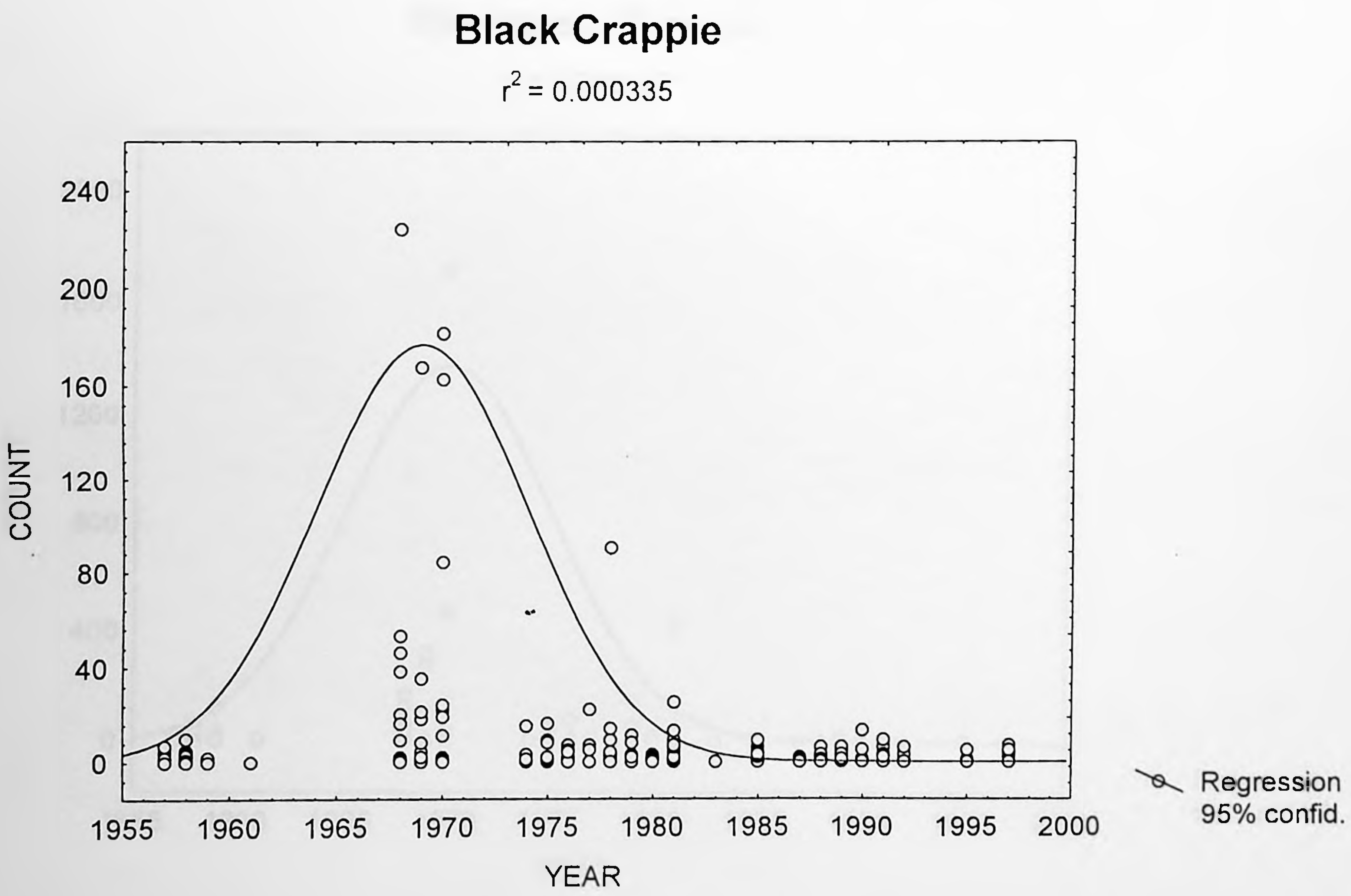

Fig. 71. Species showing a density peak along the entire river.

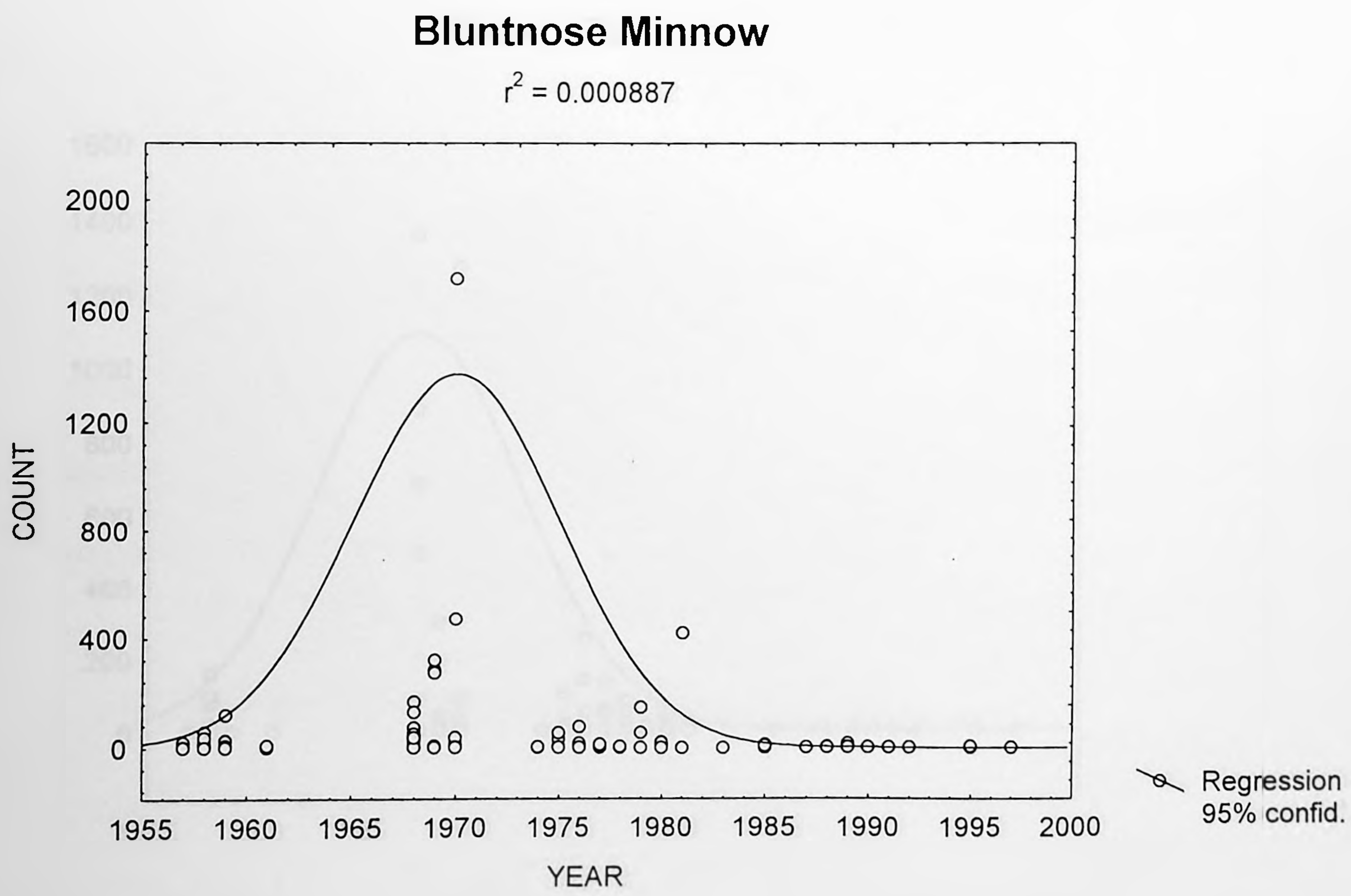

Fig. 72. Species showing a density peak along the entire river.

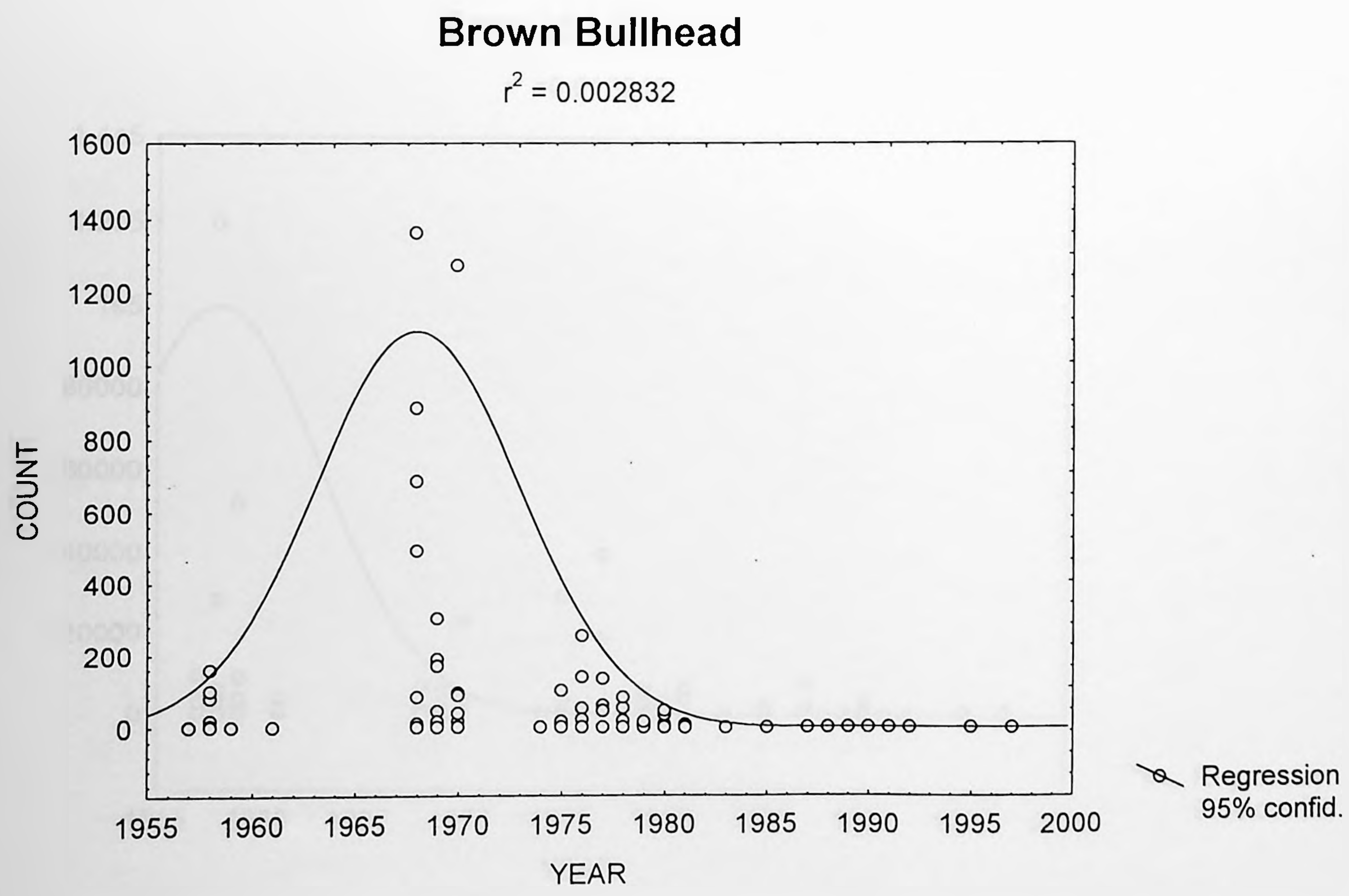

Fig. 73. Species showing a density peak along the entire river.

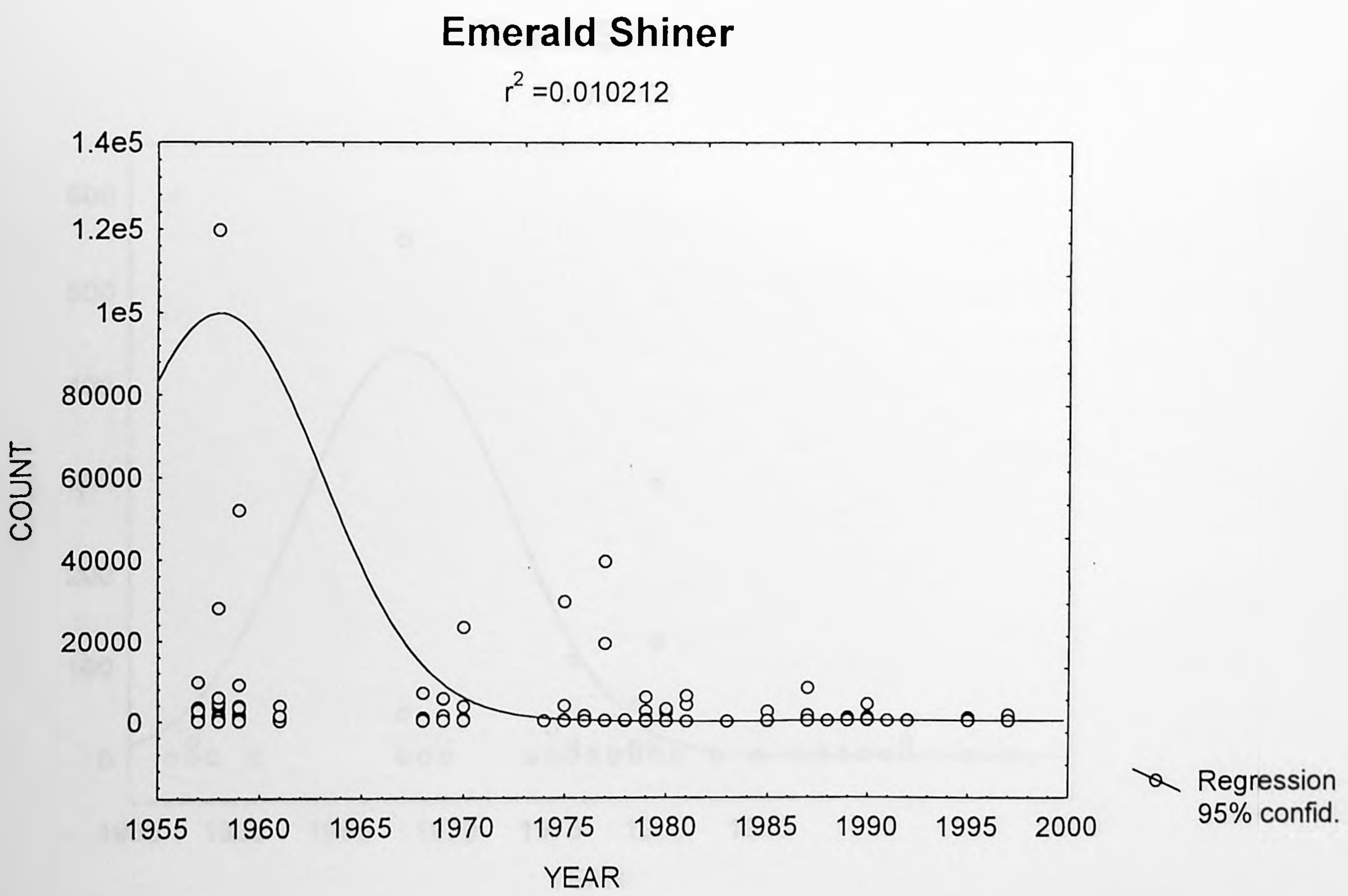

Fig. 74. Species showing a density peak along the entire river.

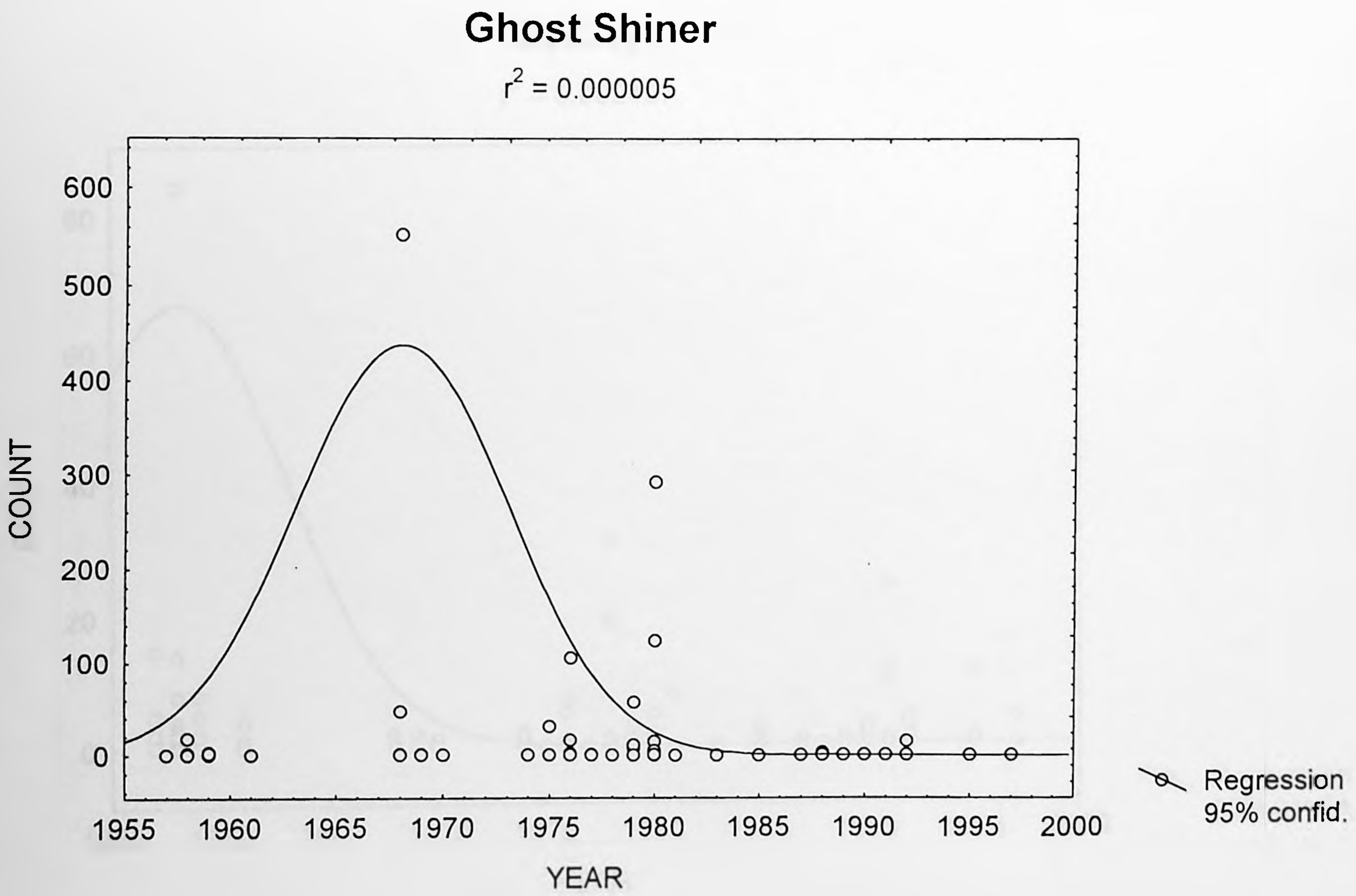

Fig. 75. Species showing a density peak along the entire river.

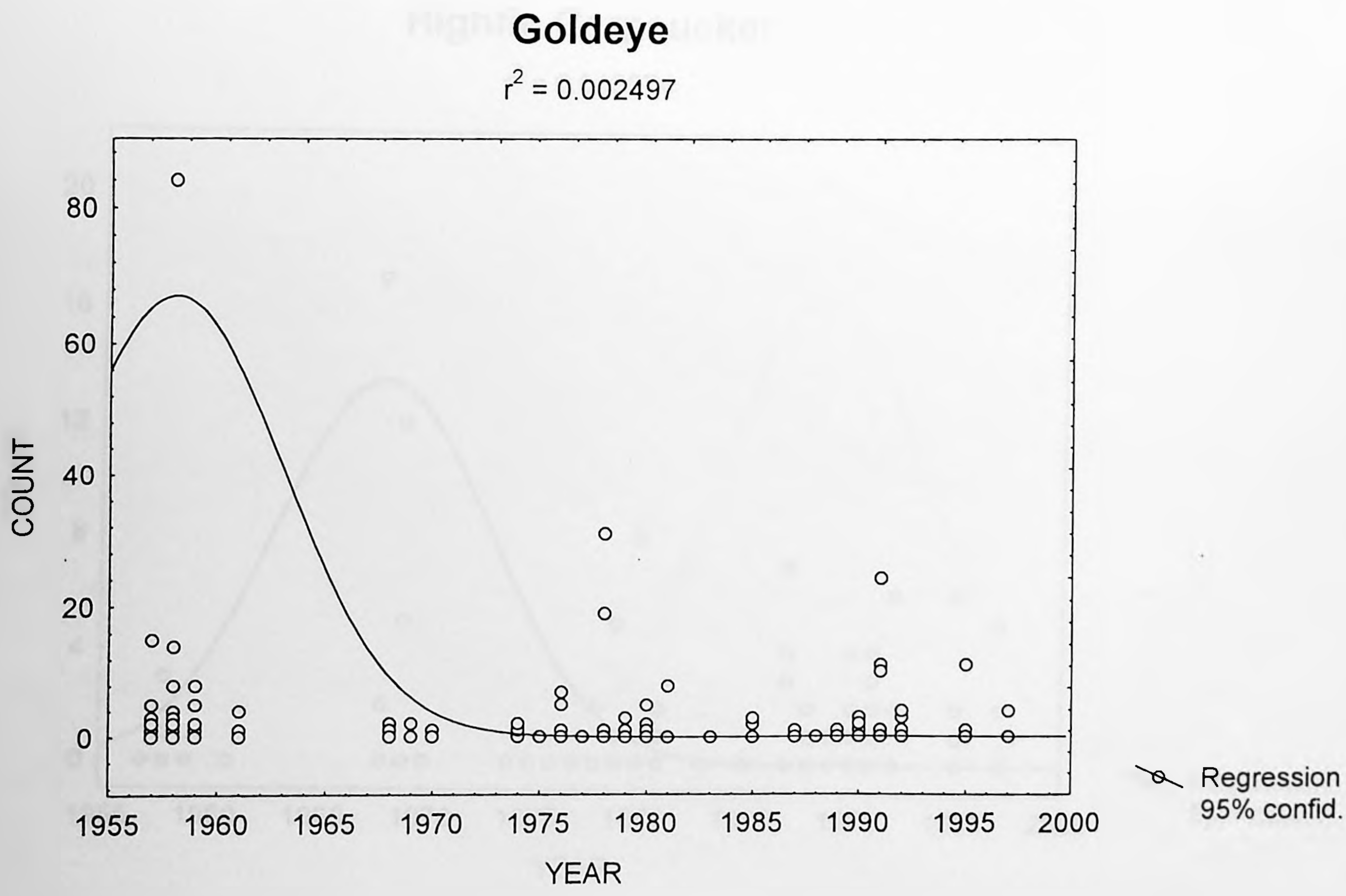

Fig. 76. Species showing a density peak along the entire river.

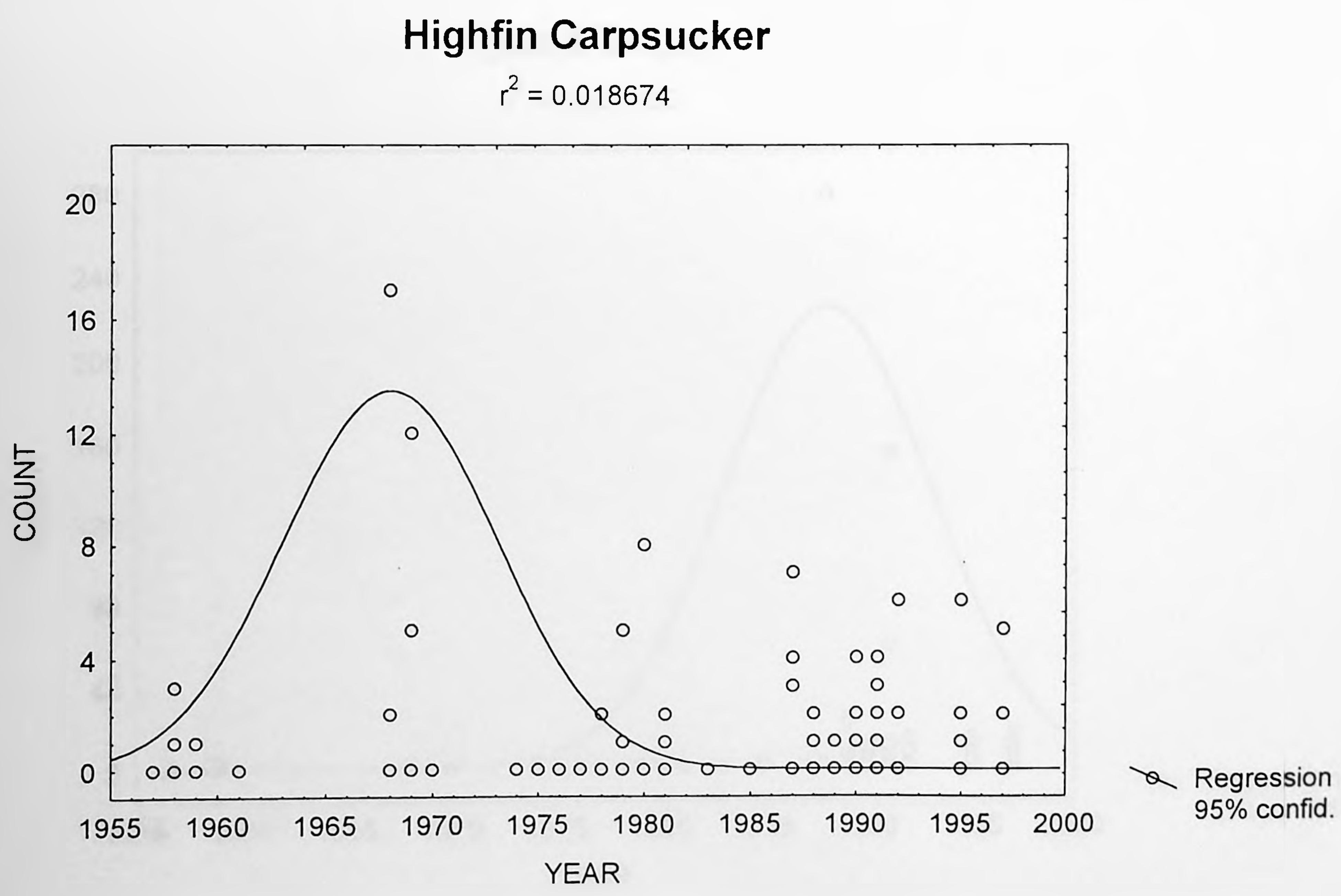

Fig. 77. Species showing a density peak along the entire river.

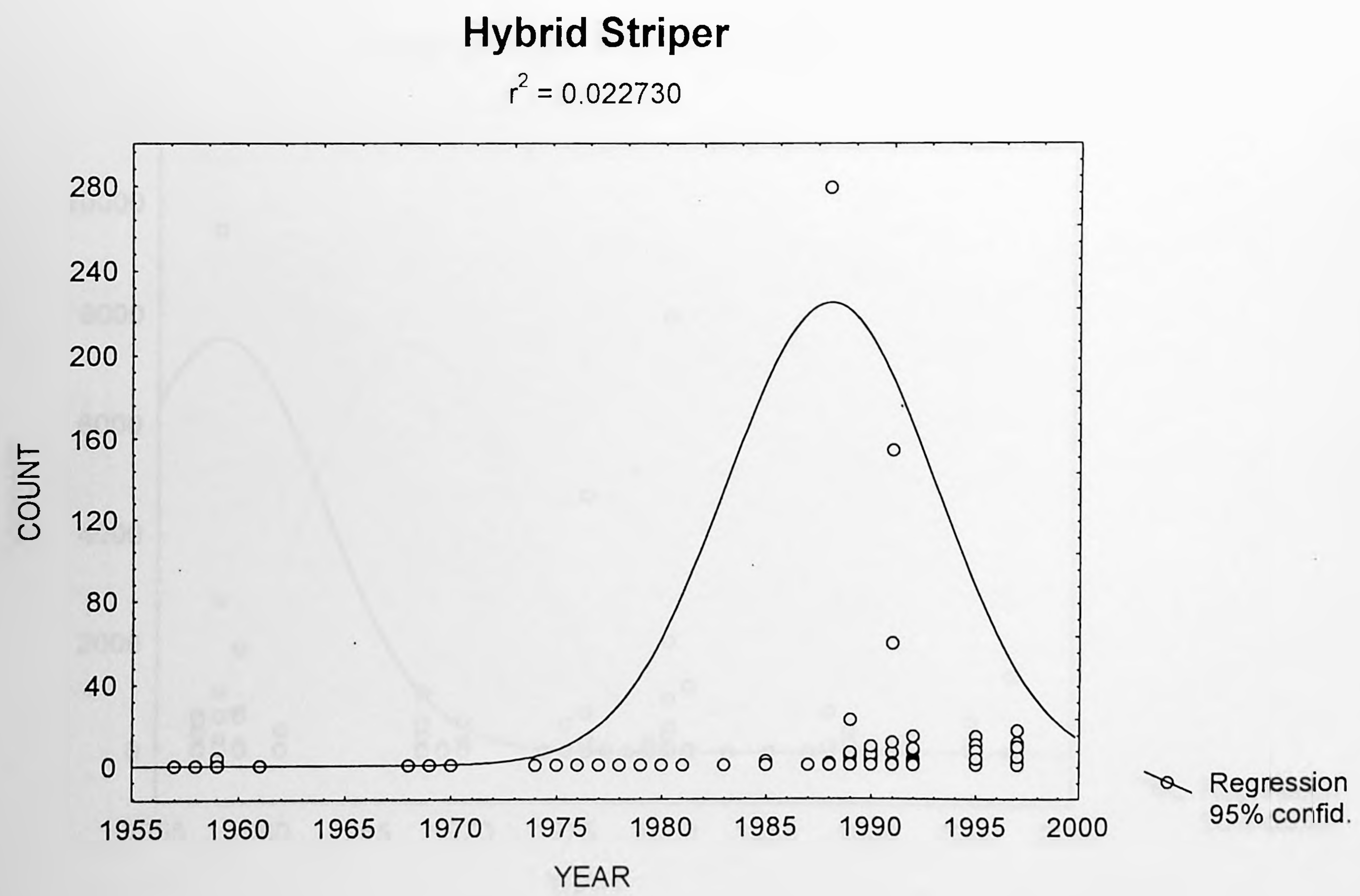

Fig. 78. Species showing a density peak along the entire river.

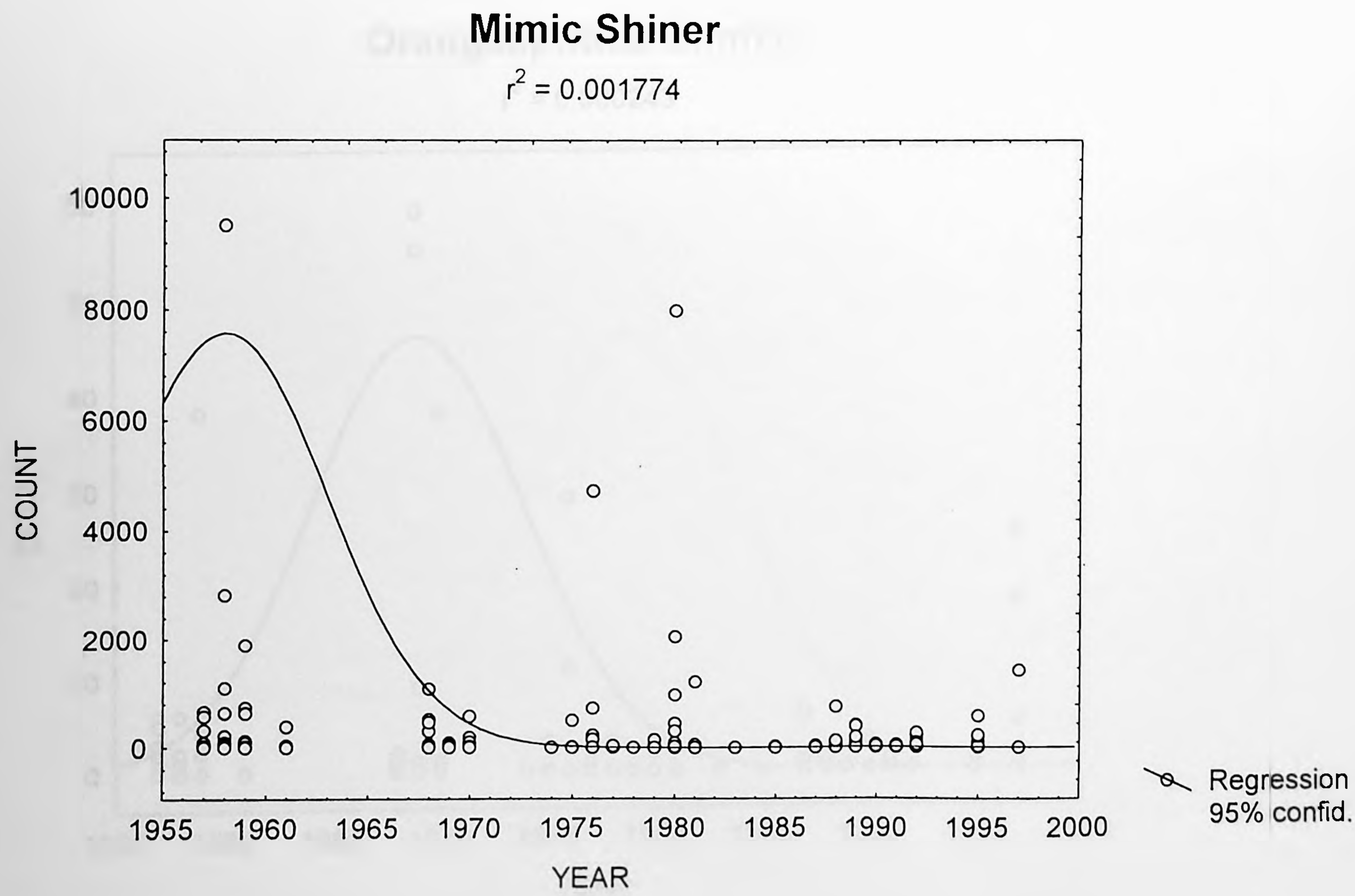

Fig. 79. Species showing a density peak along the entire river.

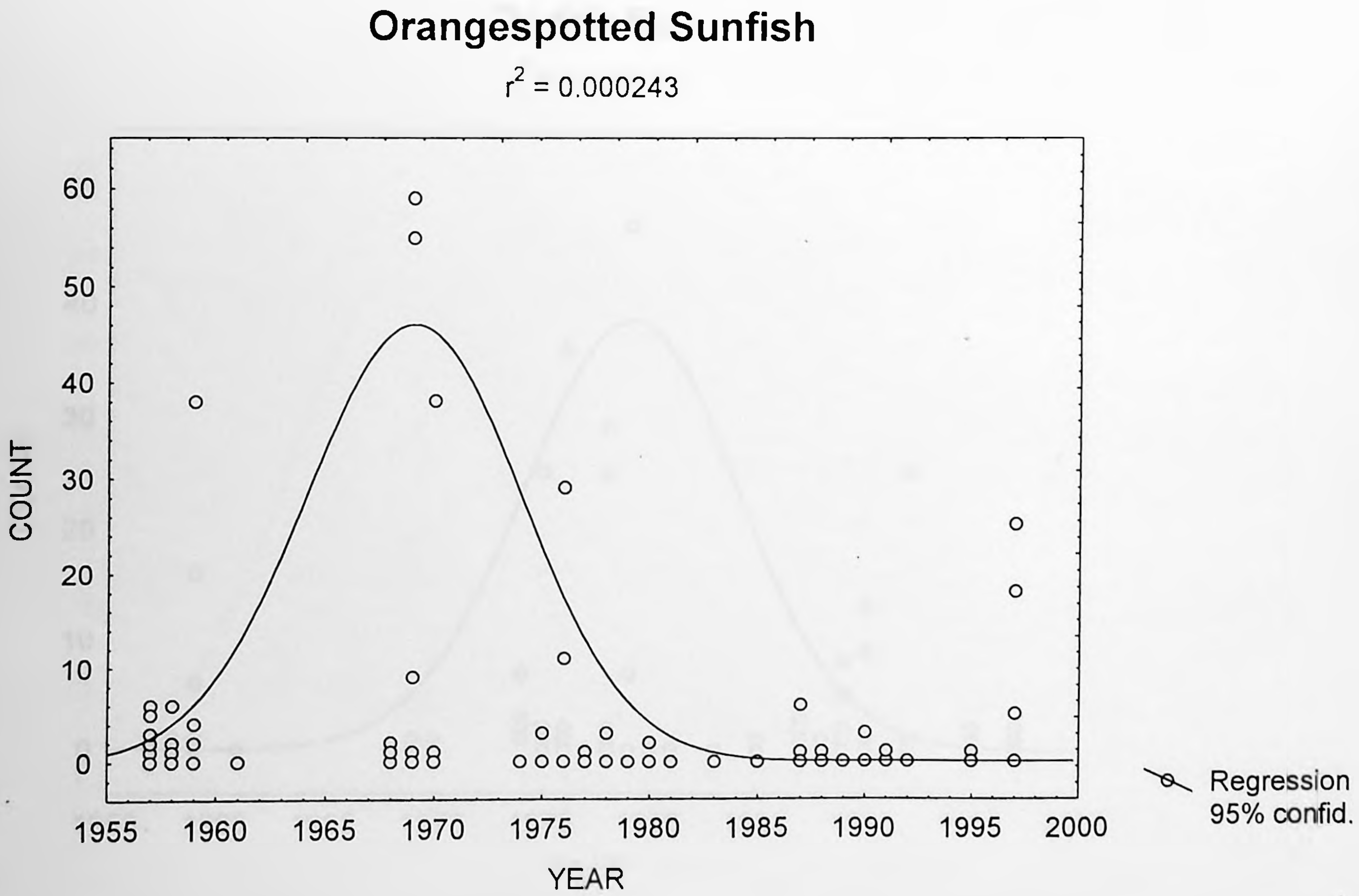

Fig. 80. Species showing a density peak along the entire river.

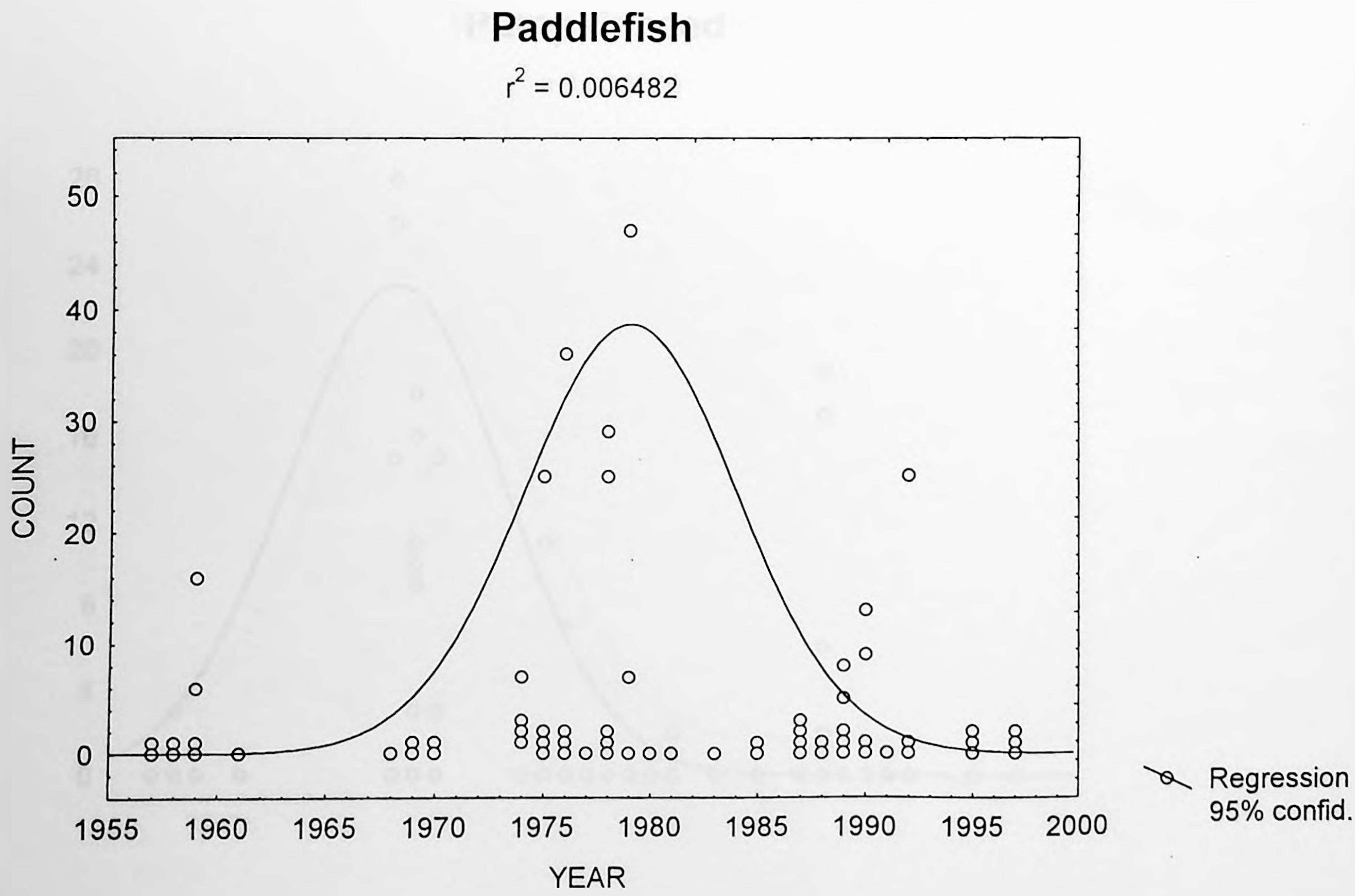

Fig. 81. Species showing a density peak along the entire river.

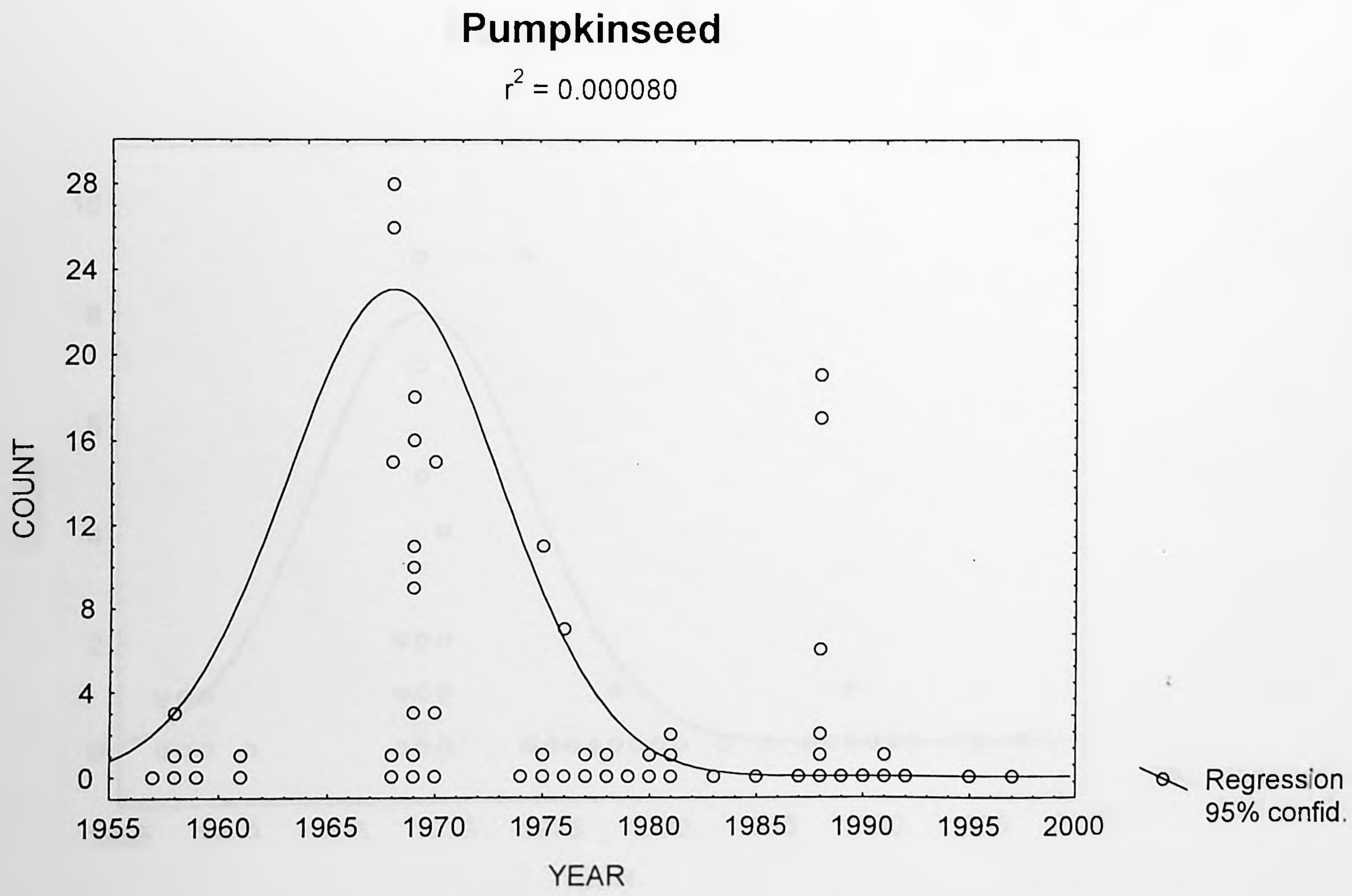

Fig. 82. Species showing a density peak along the entire river.

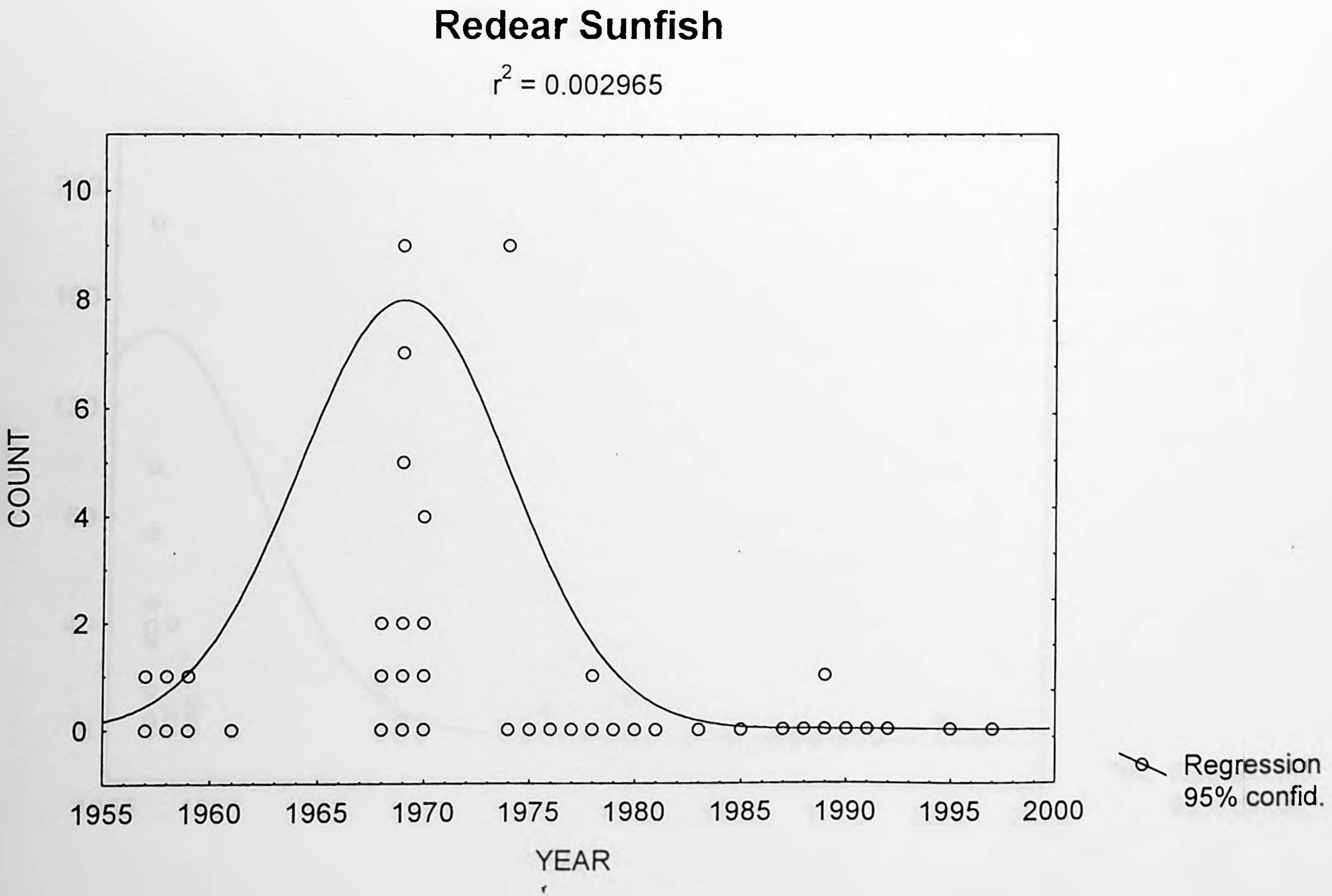

Fig. 83. Species showing a density peak along the entire river.

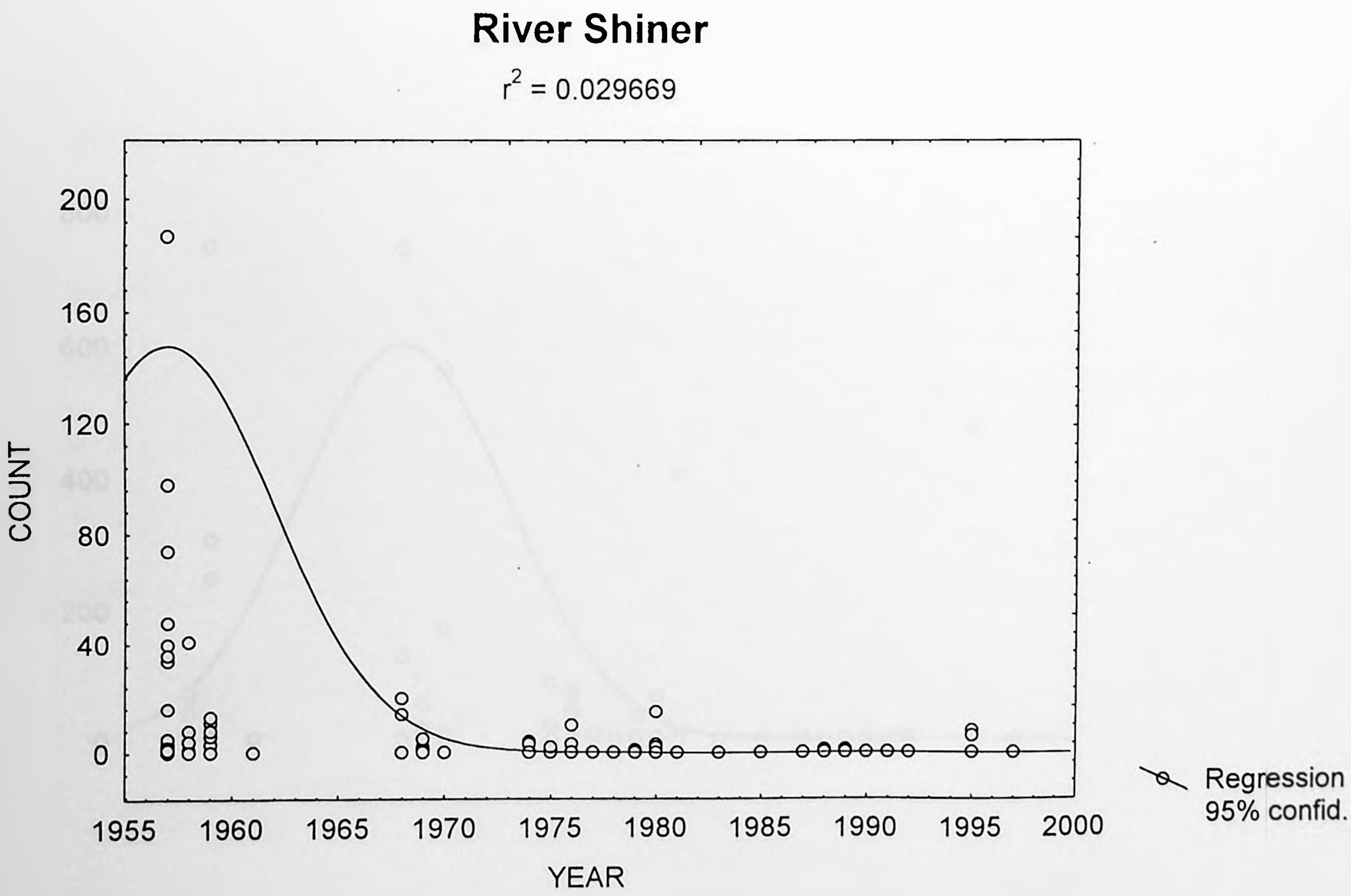

Fig. 84. Species showing a density peak along the entire river.

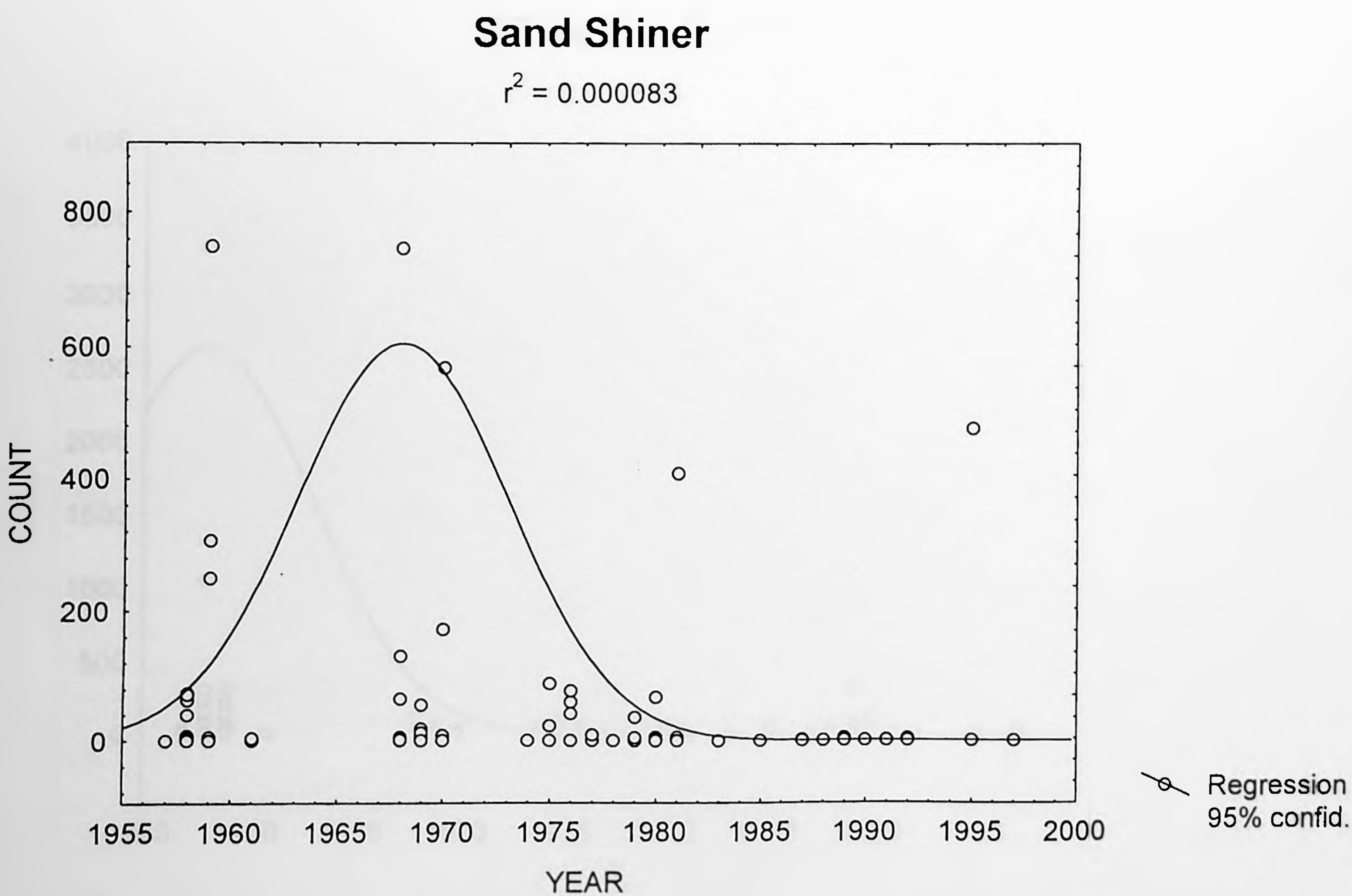

Fig. 85. Species showing a density peak along the entire river.

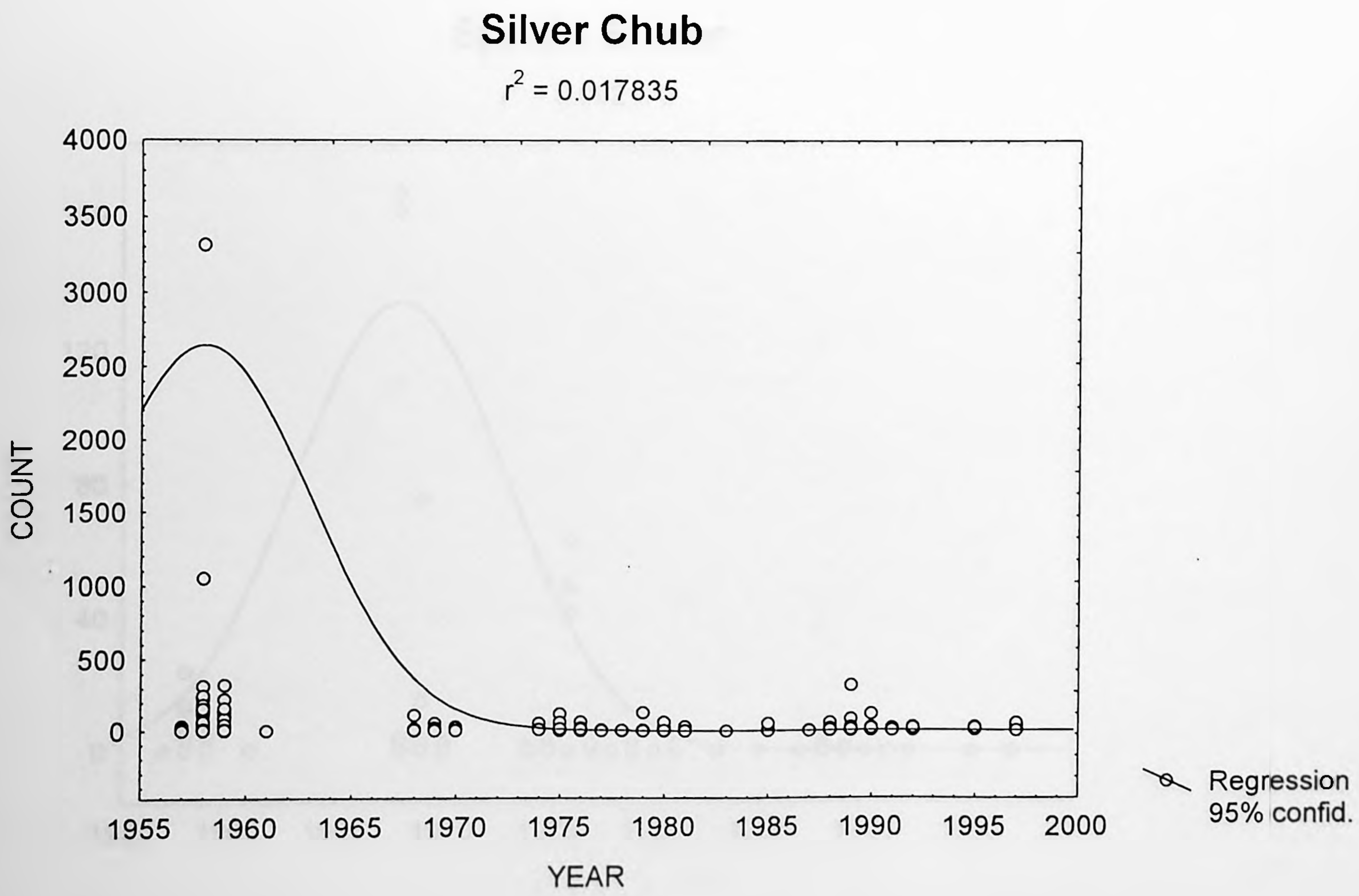

Fig. 86. Species showing a density peak along the entire river.

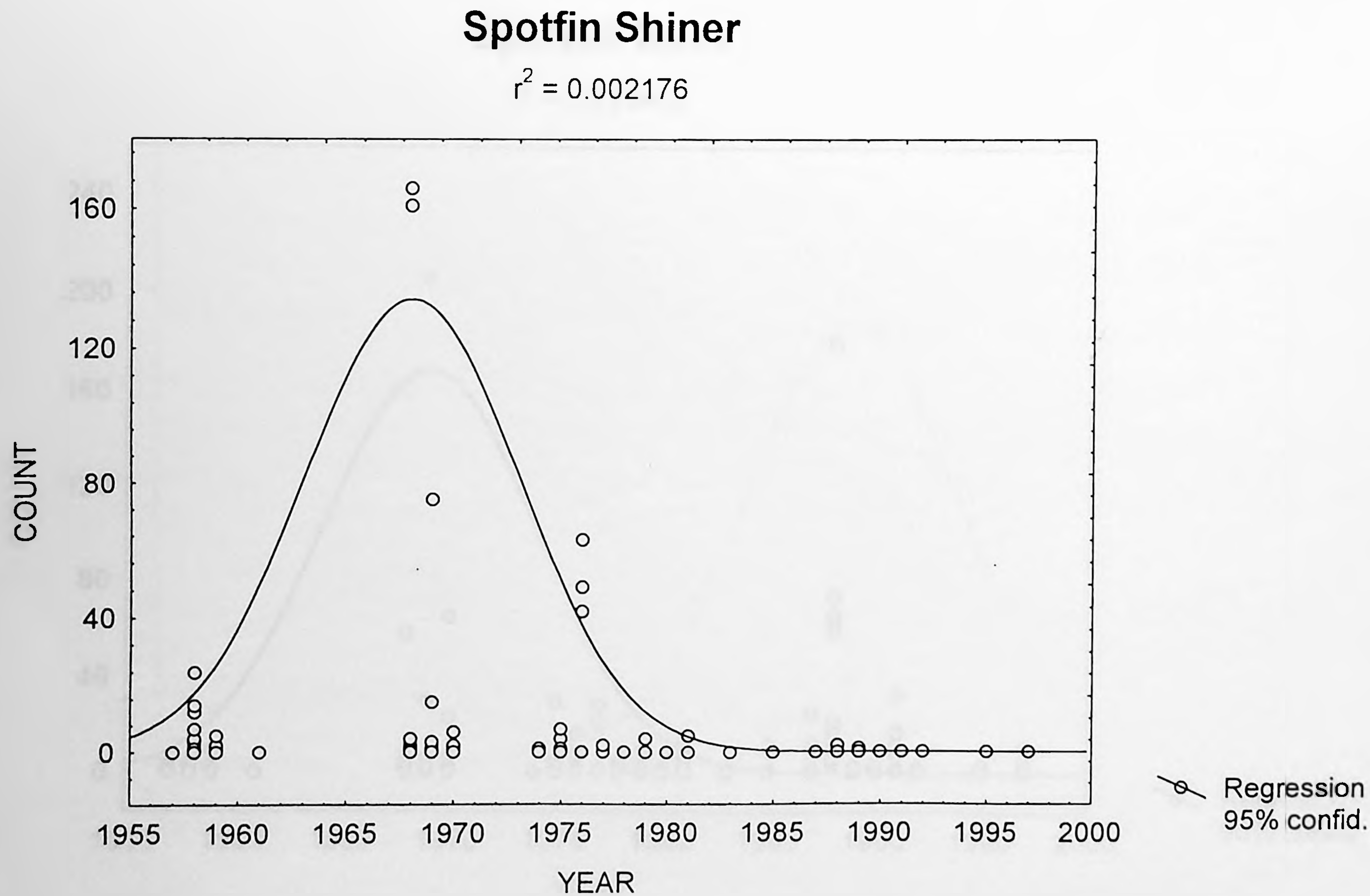

Fig. 87. Species showing a density peak along the entire river.

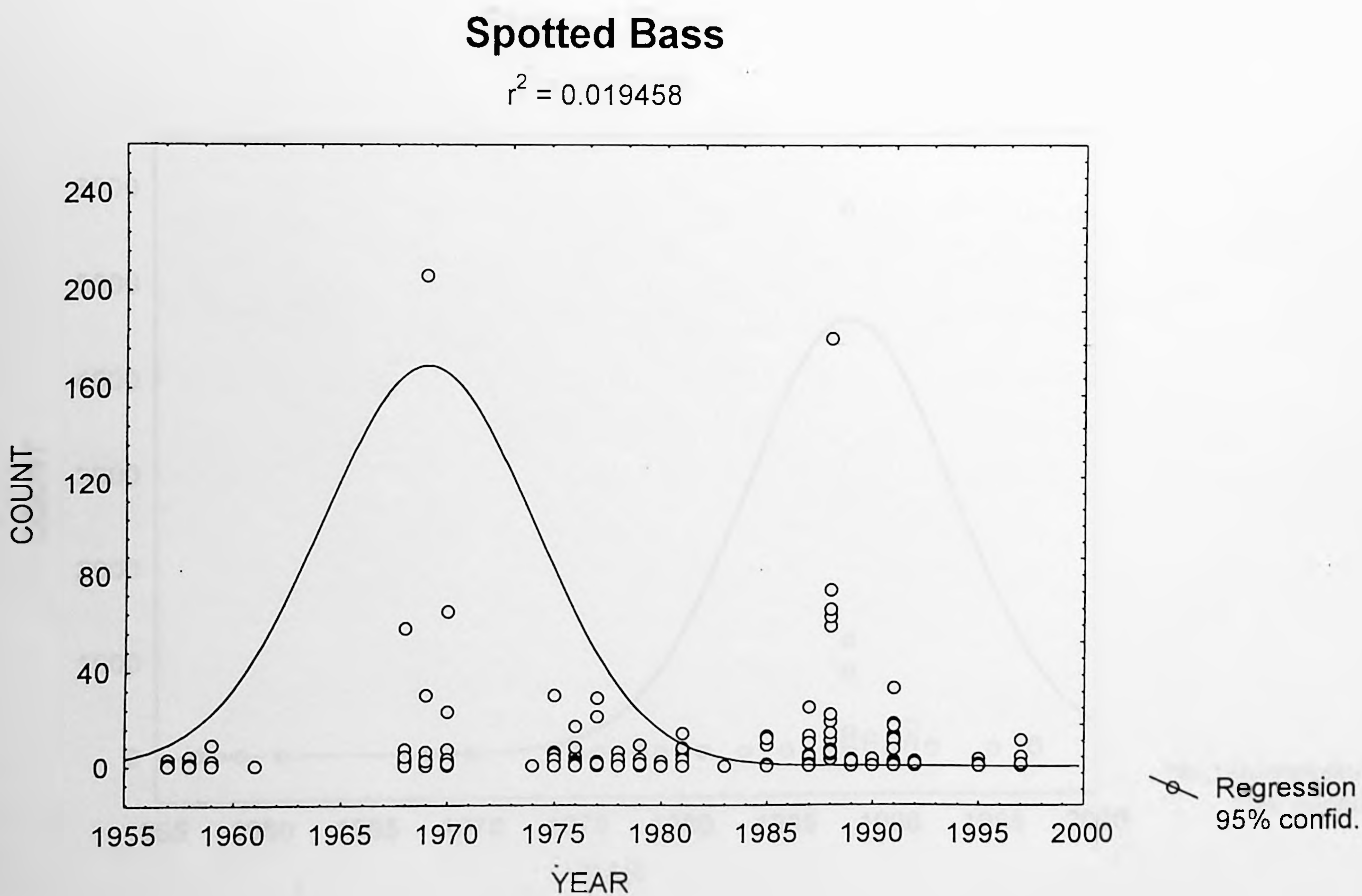

Fig. 88. Species showing a density peak along the entire river.

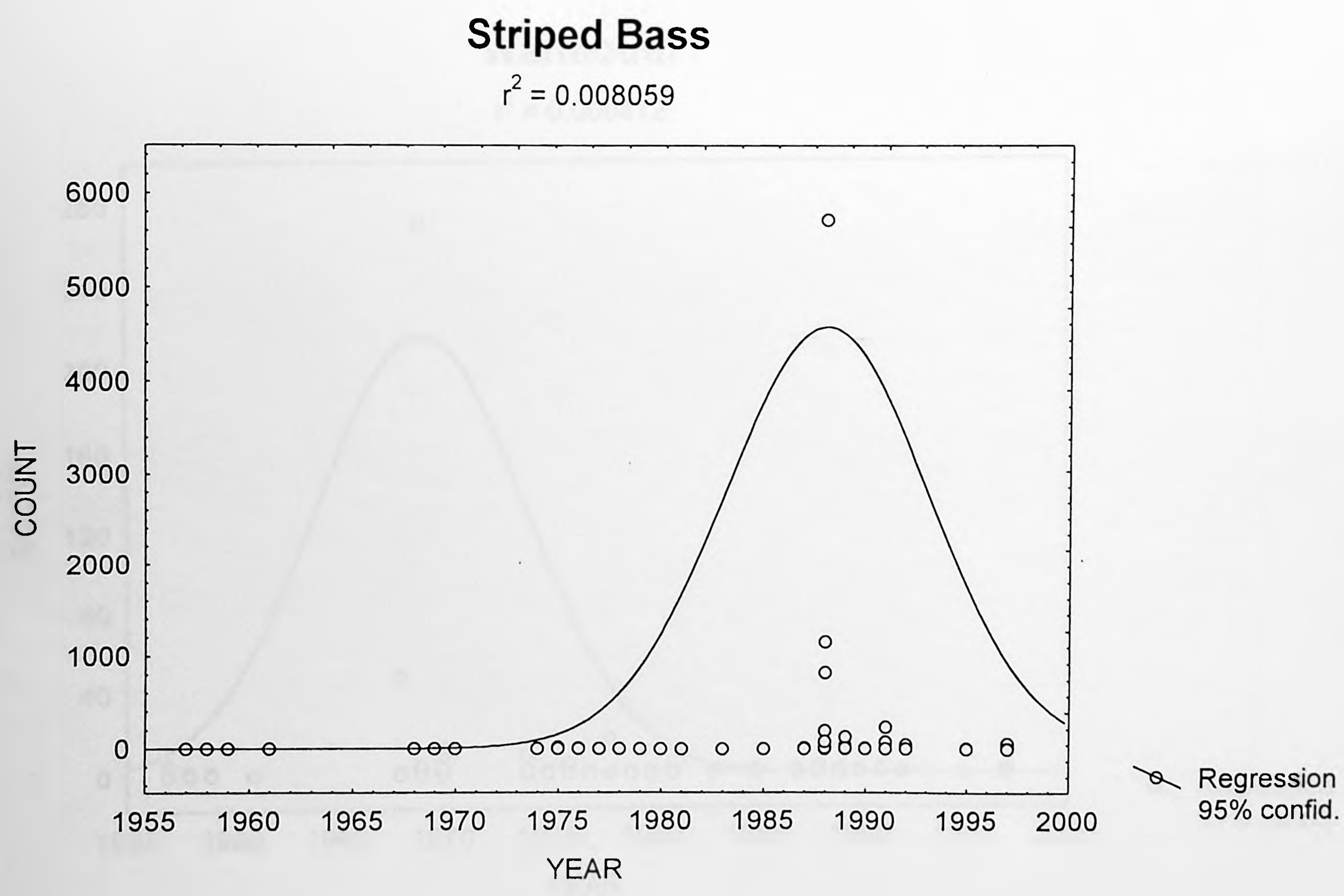

Fig. 89. Species showing a density peak along the entire river.

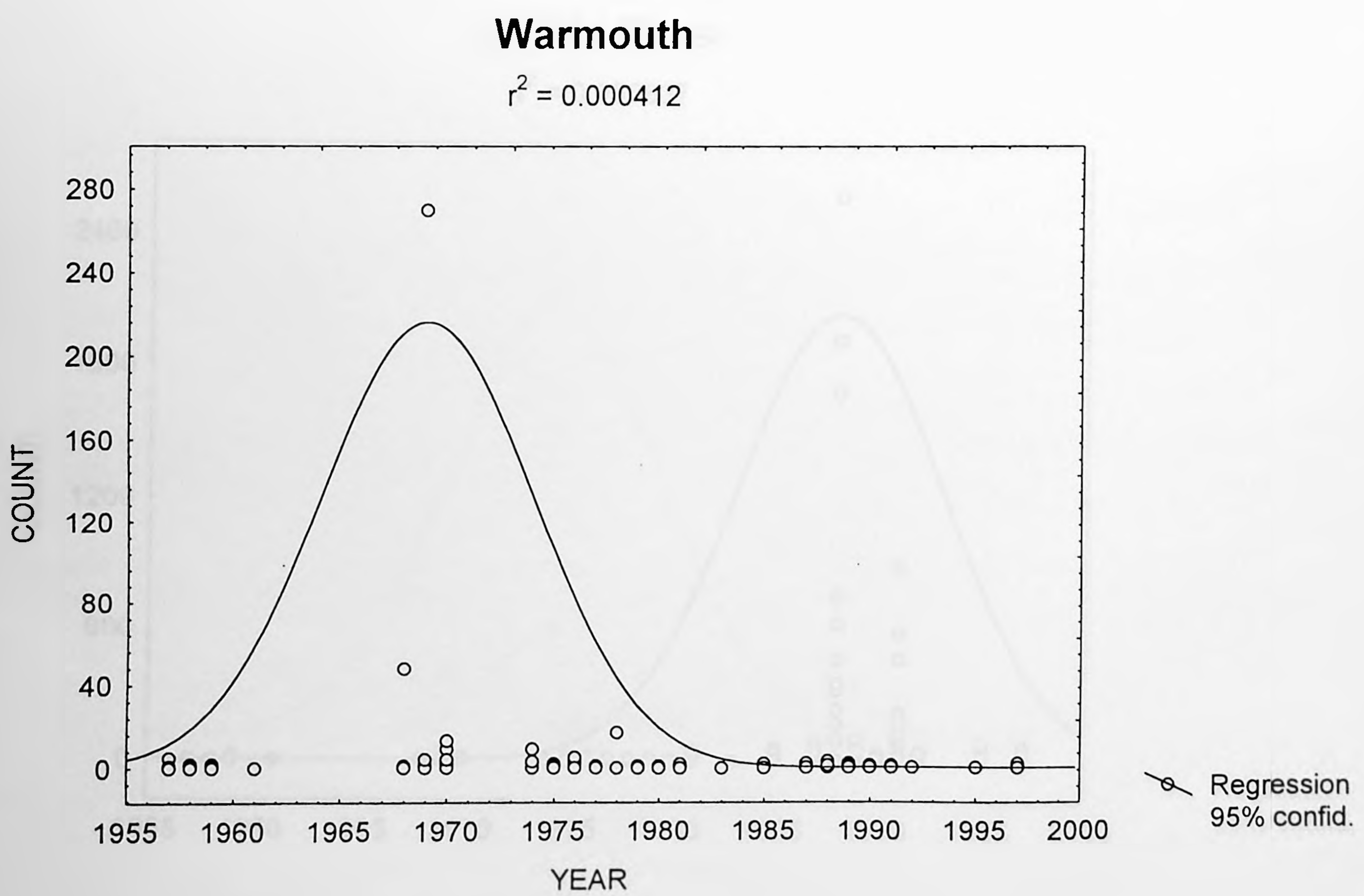

Fig. 90. Species showing a density peak along the entire river.

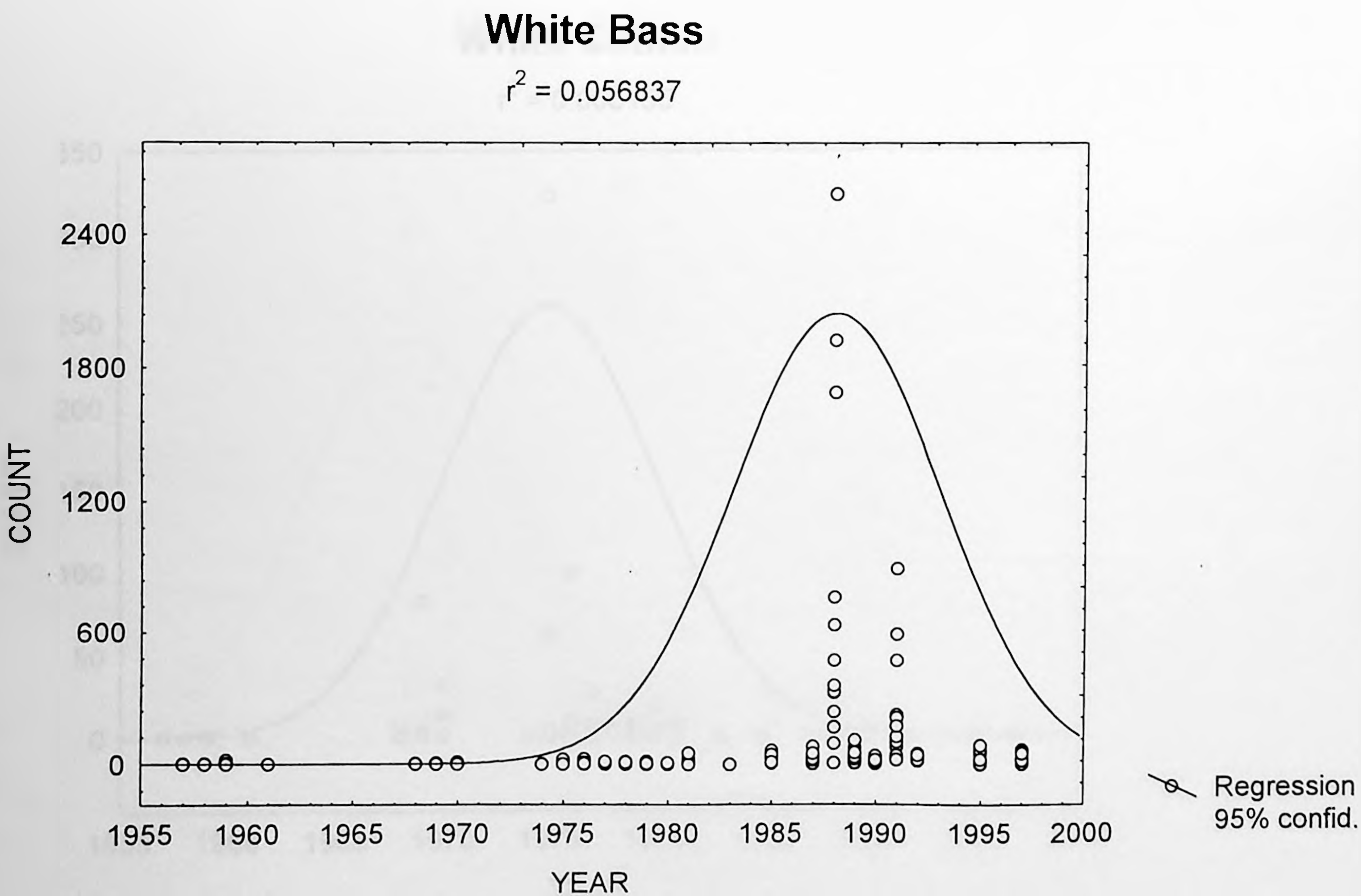

Fig. 91. Species showing a density peak along the entire river.

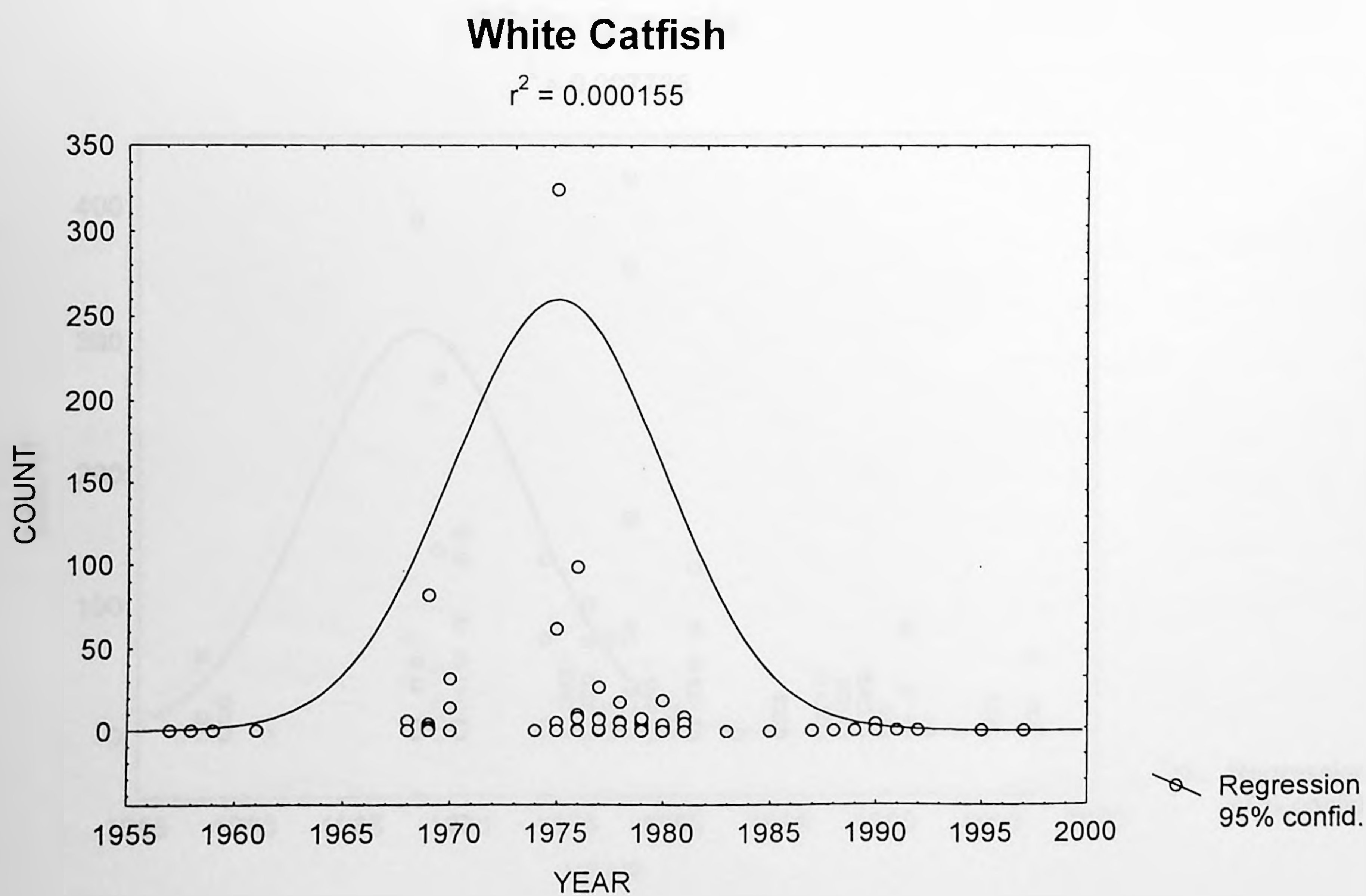

Fig. 92. Species showing a density peak along the entire river.

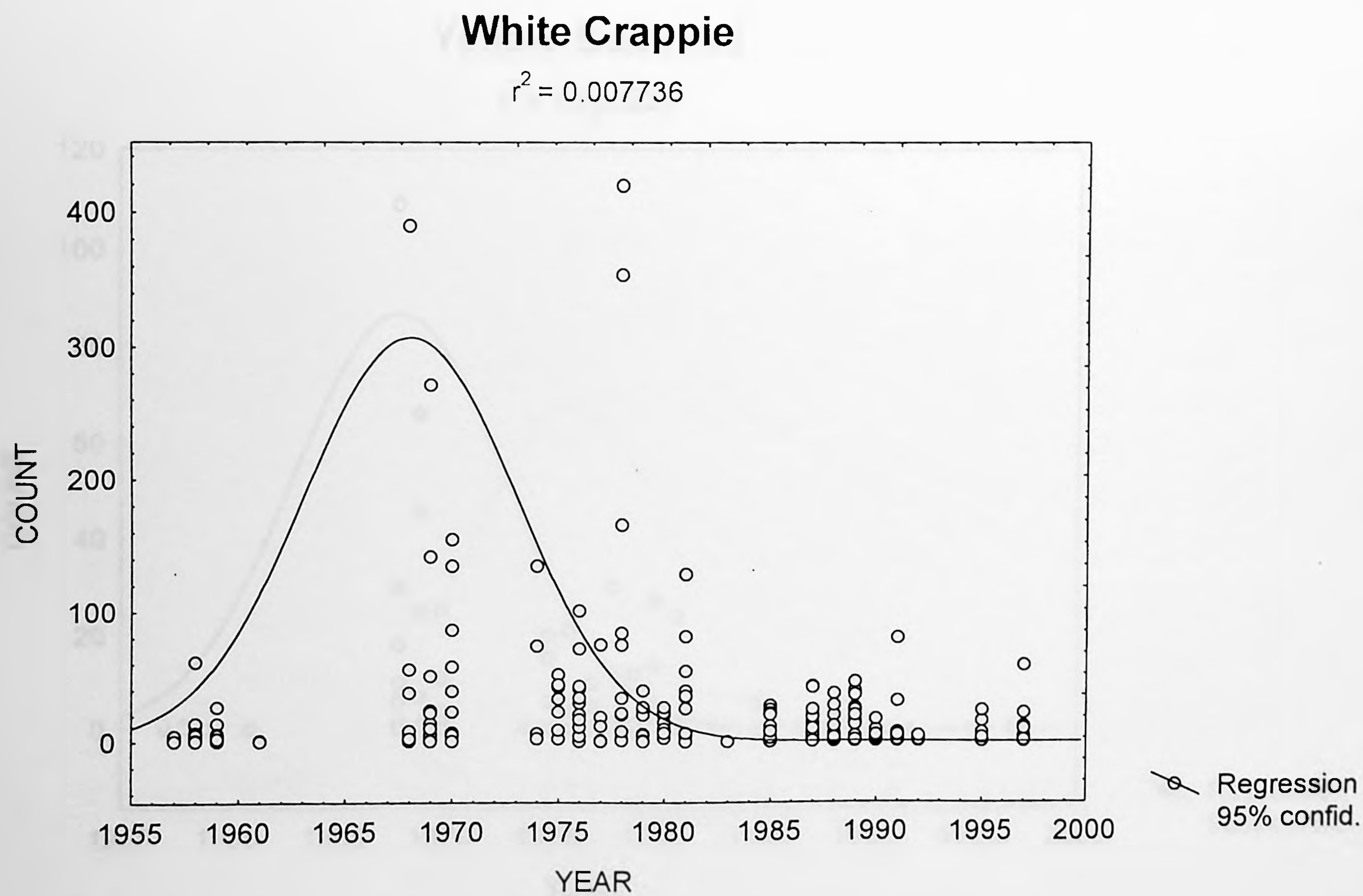

Fig. 93. Species showing a density peak along the entire river.

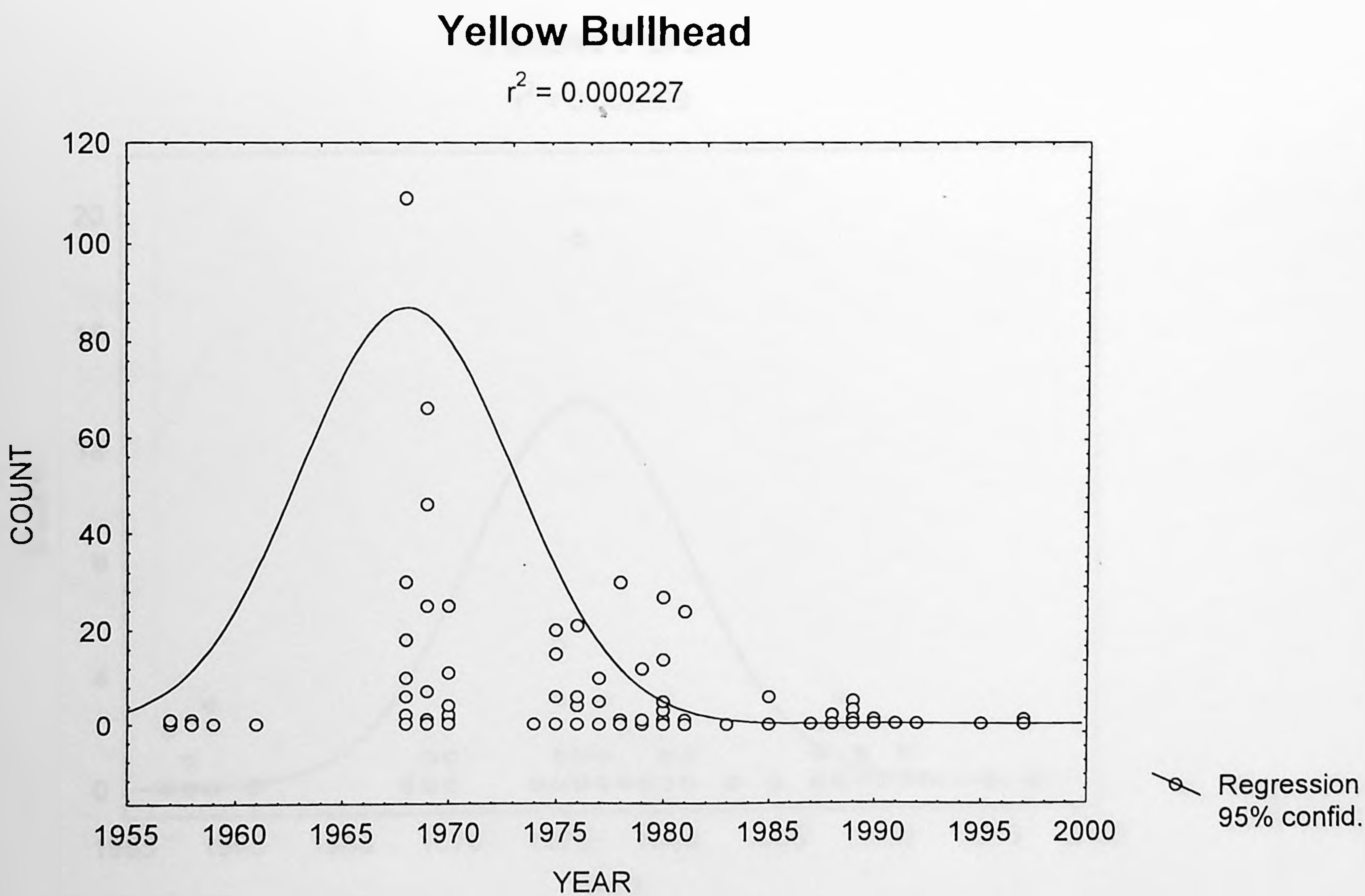

Fig. 94. Species showing a density peak along the entire river.

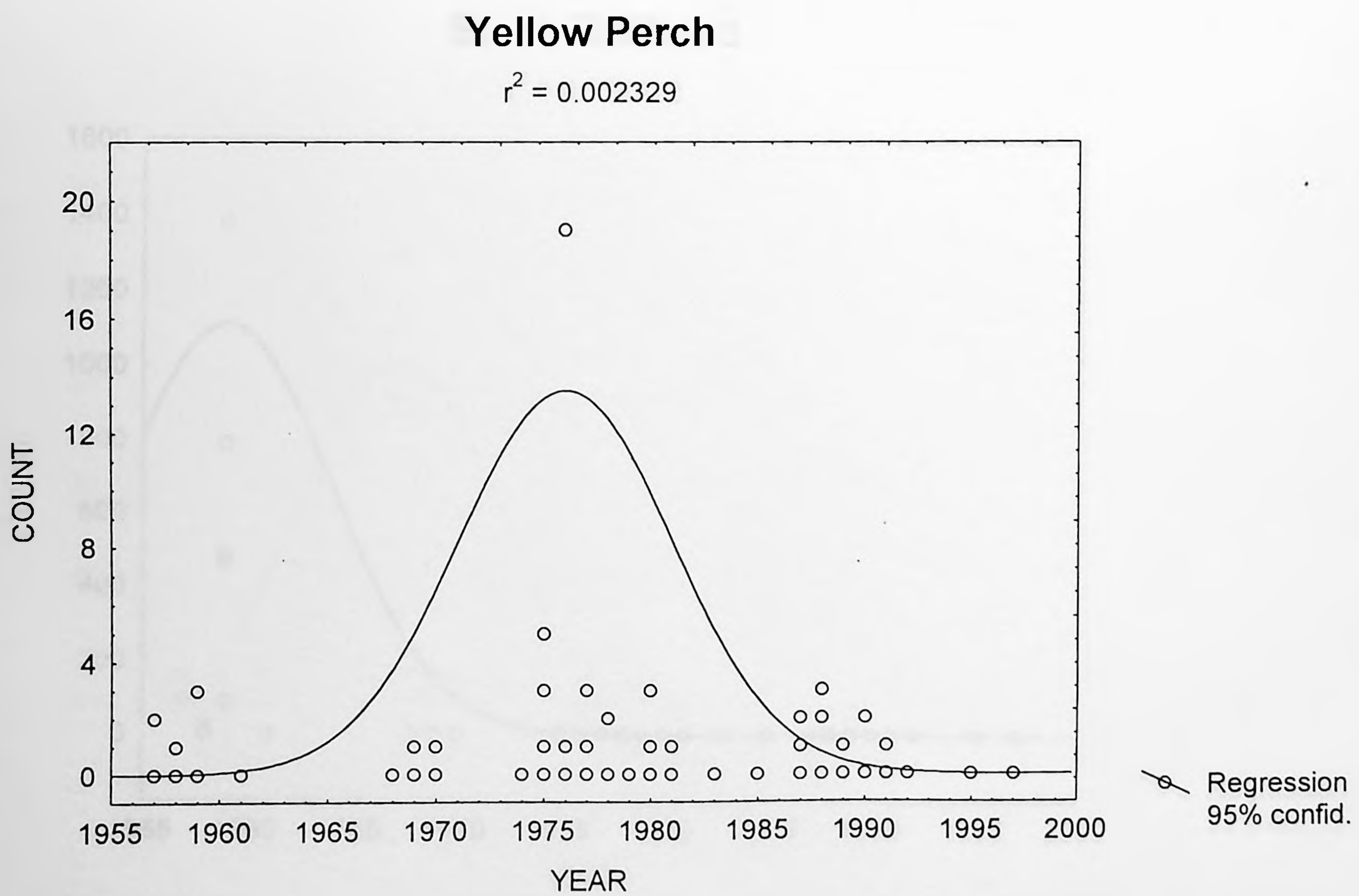

Fig. 95. Species showing a density peak along the entire river.

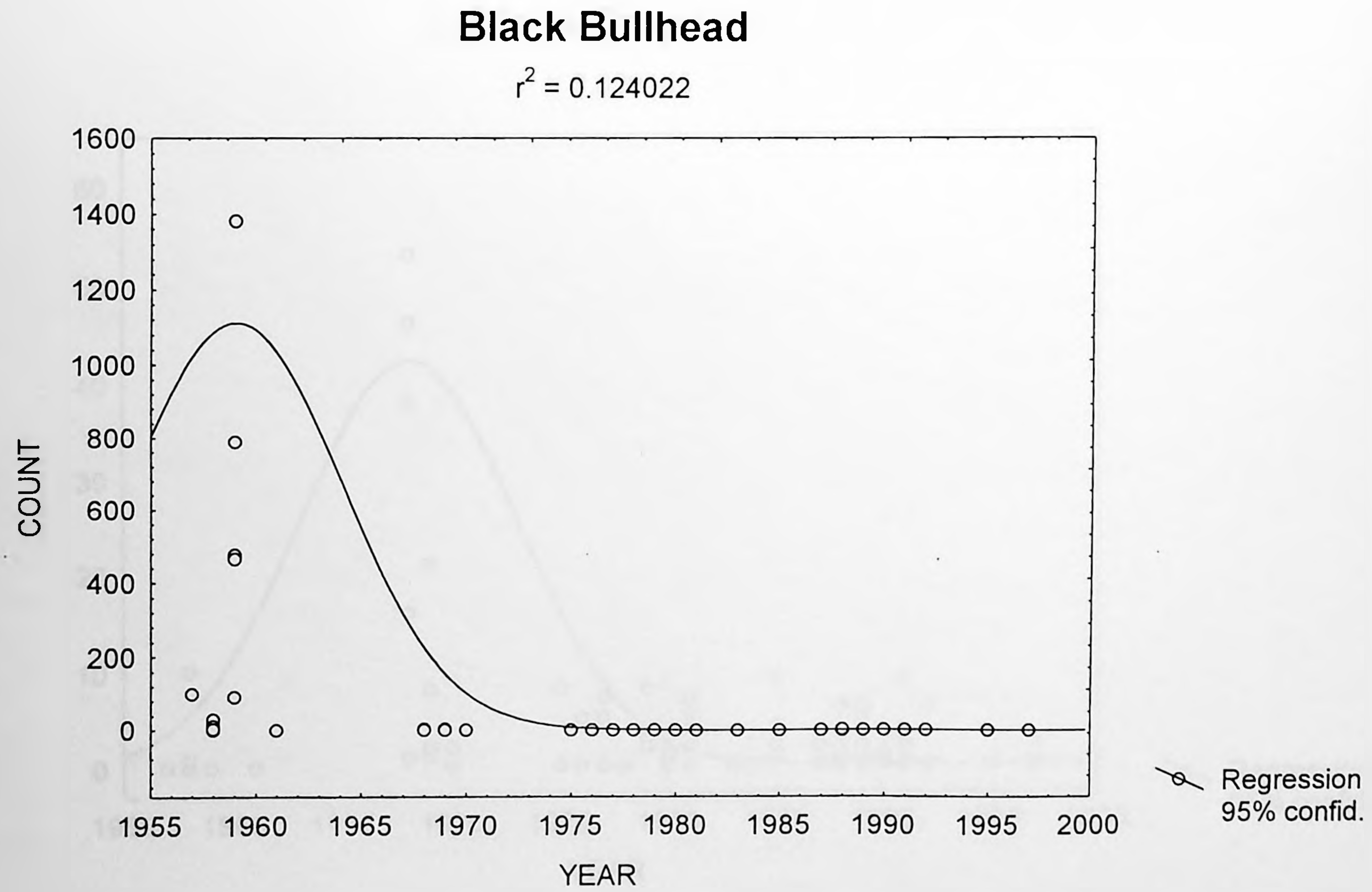

Fig. 96. Species showing a density peak along the upper river section.

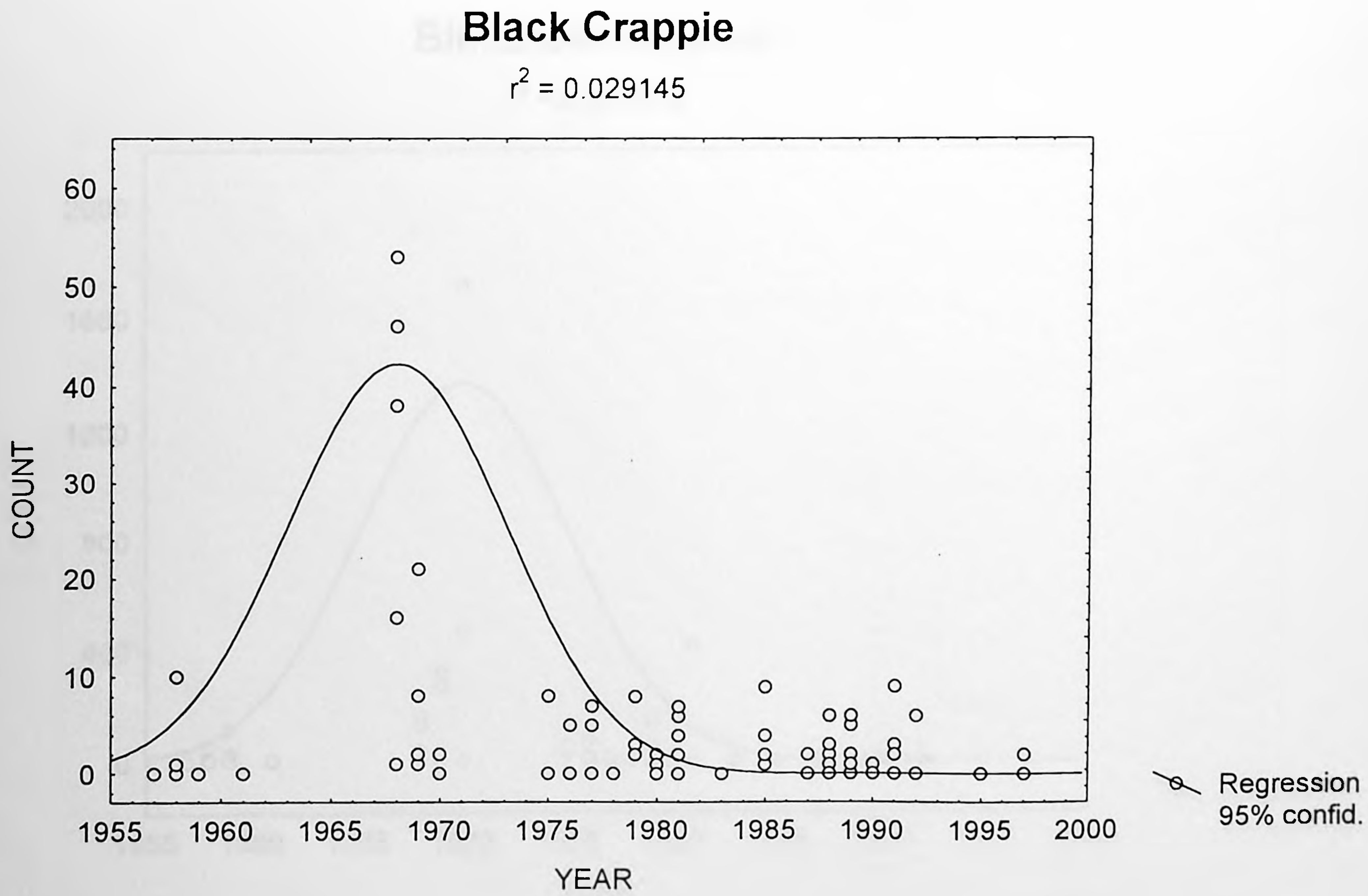

Fig. 97. Species showing a density peak along the upper river section.

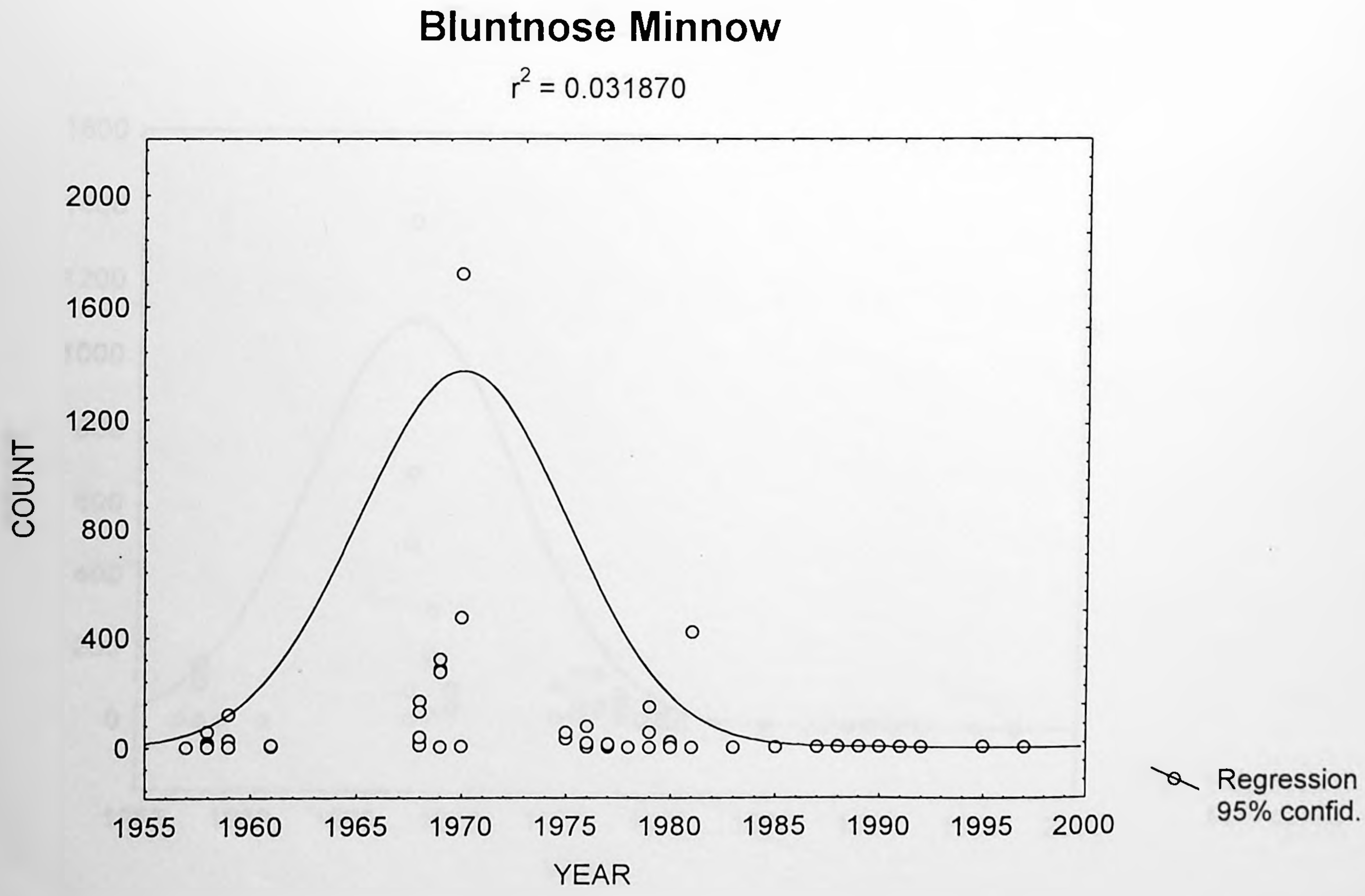

Fig. 98. Species showing a density peak along the upper river section.

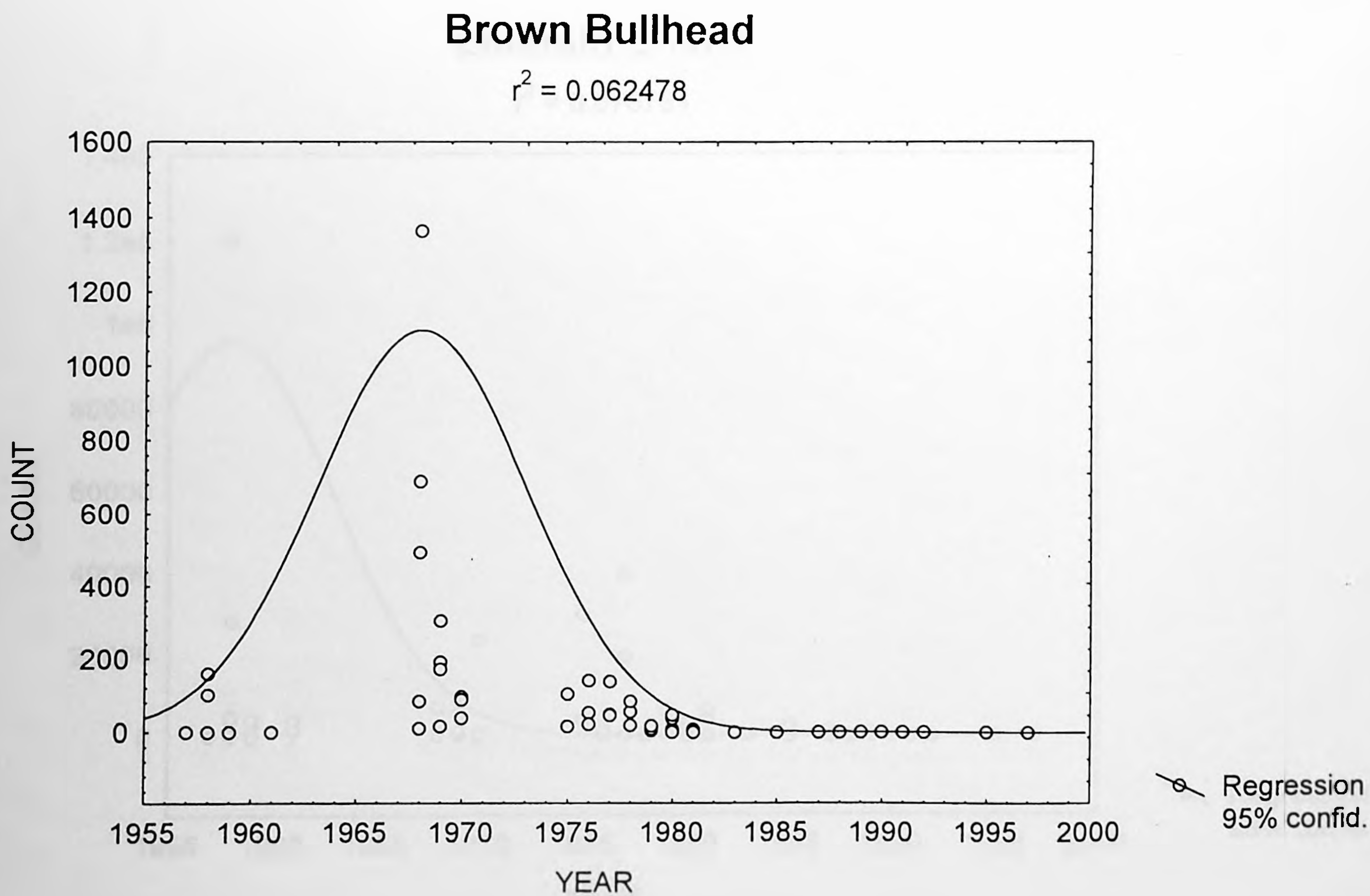

Fig. 99. Species showing a density peak along the upper river section.

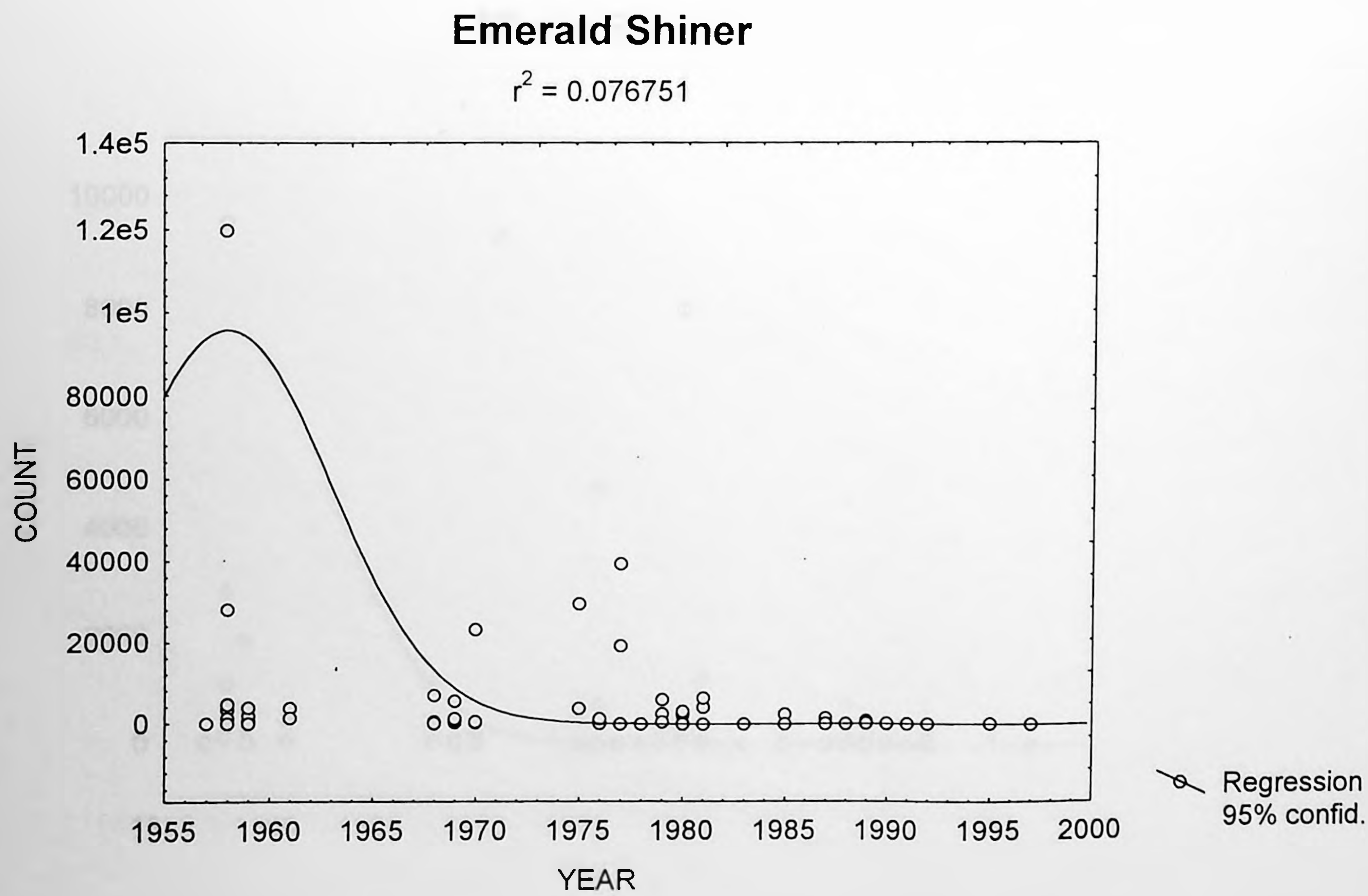

Fig. 100. Species showing a density peak along the upper river section.

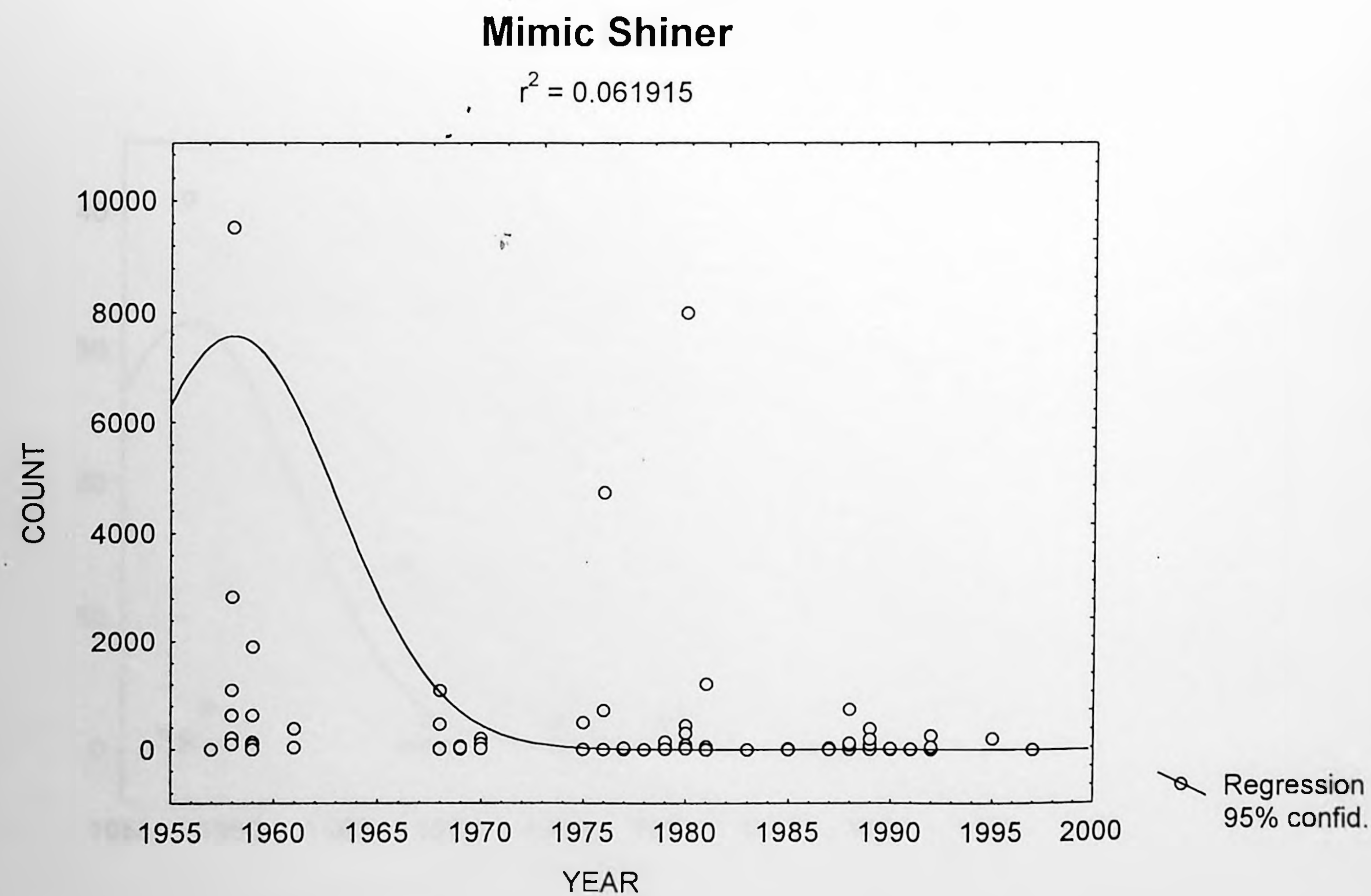

Fig. 101. Species showing a density peak along the upper river section.

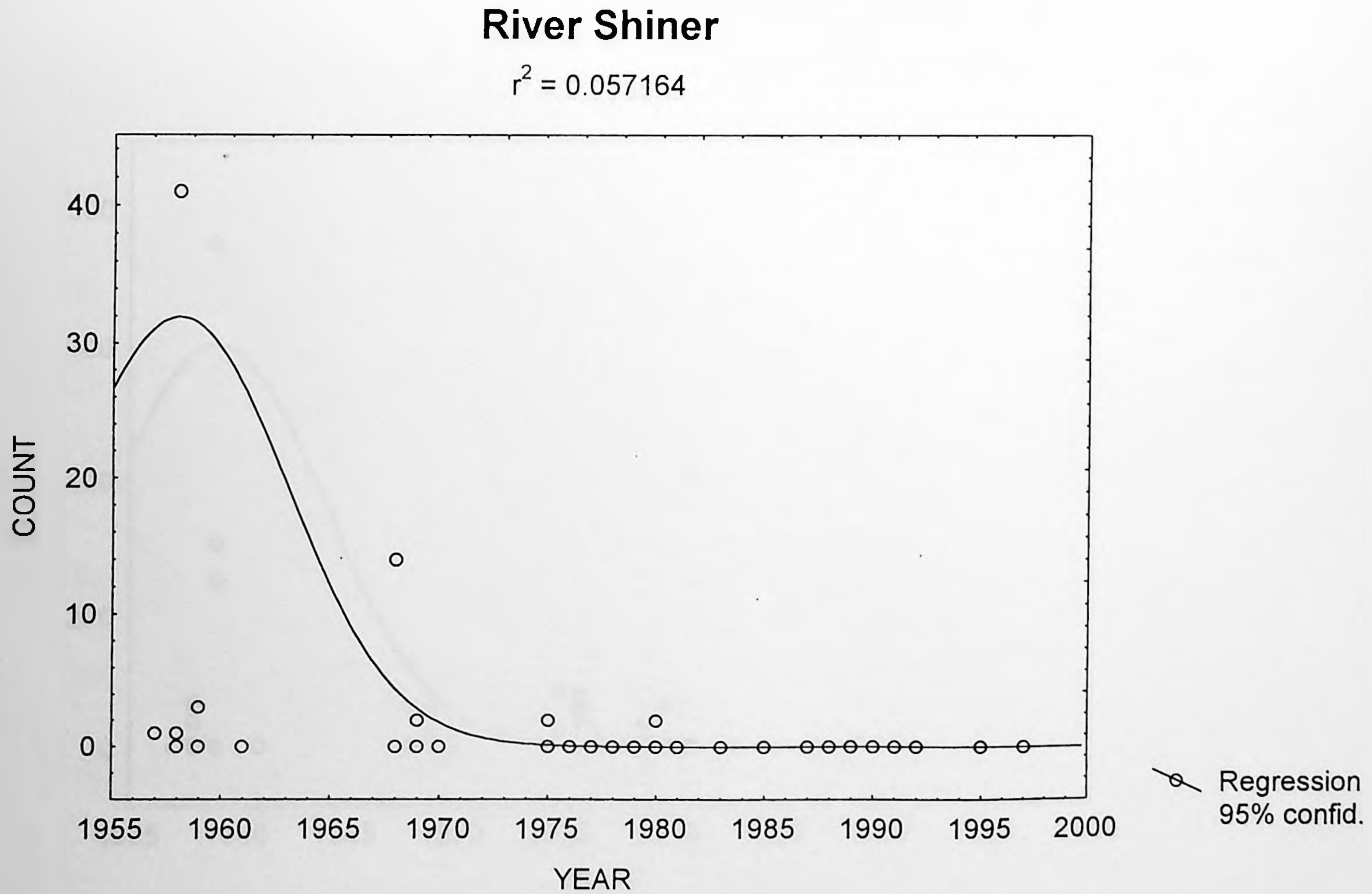

Fig. 102. Species showing a density peak along the upper river section.

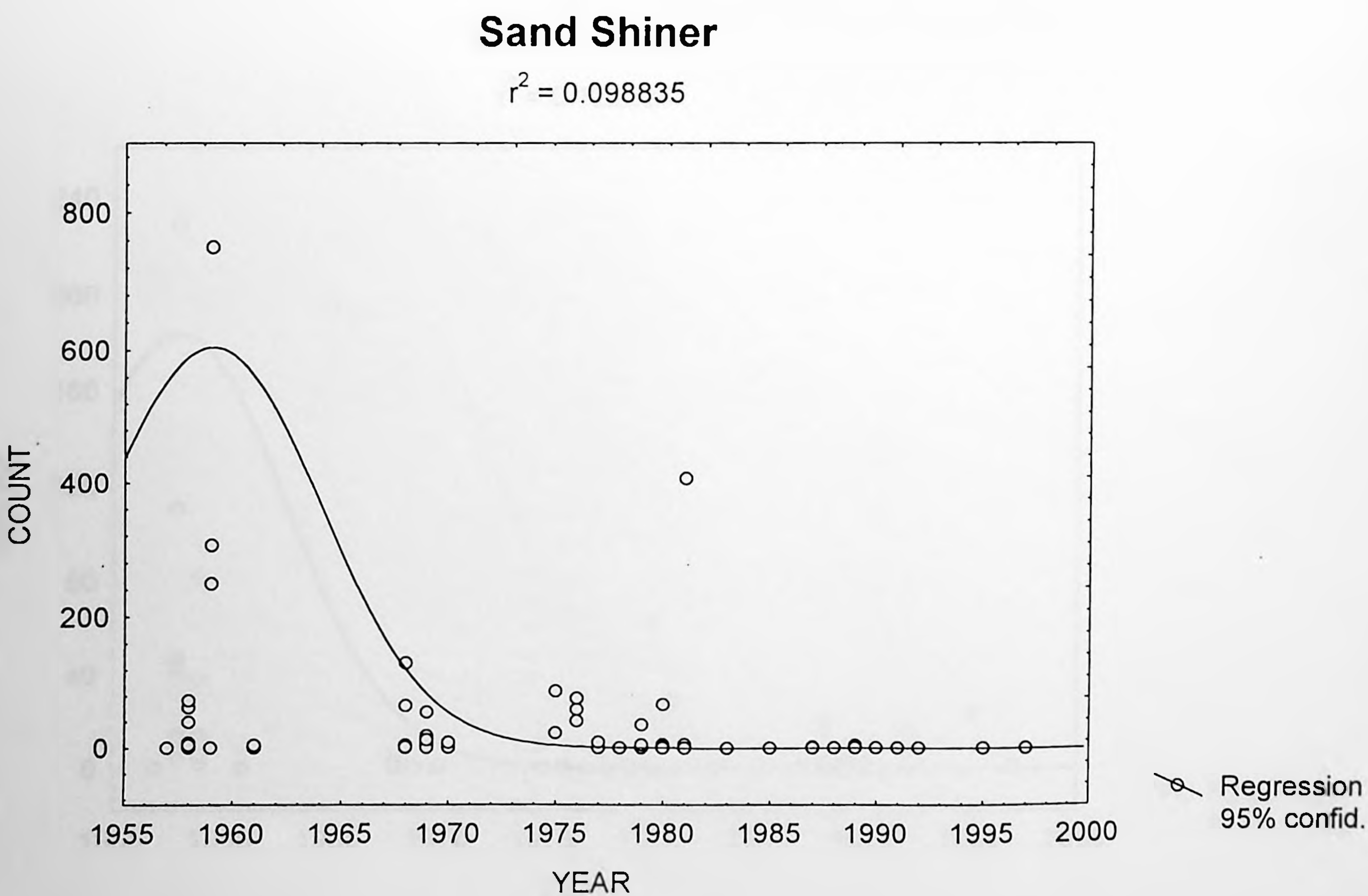

Fig. 103. Species showing a density peak along the upper river section.

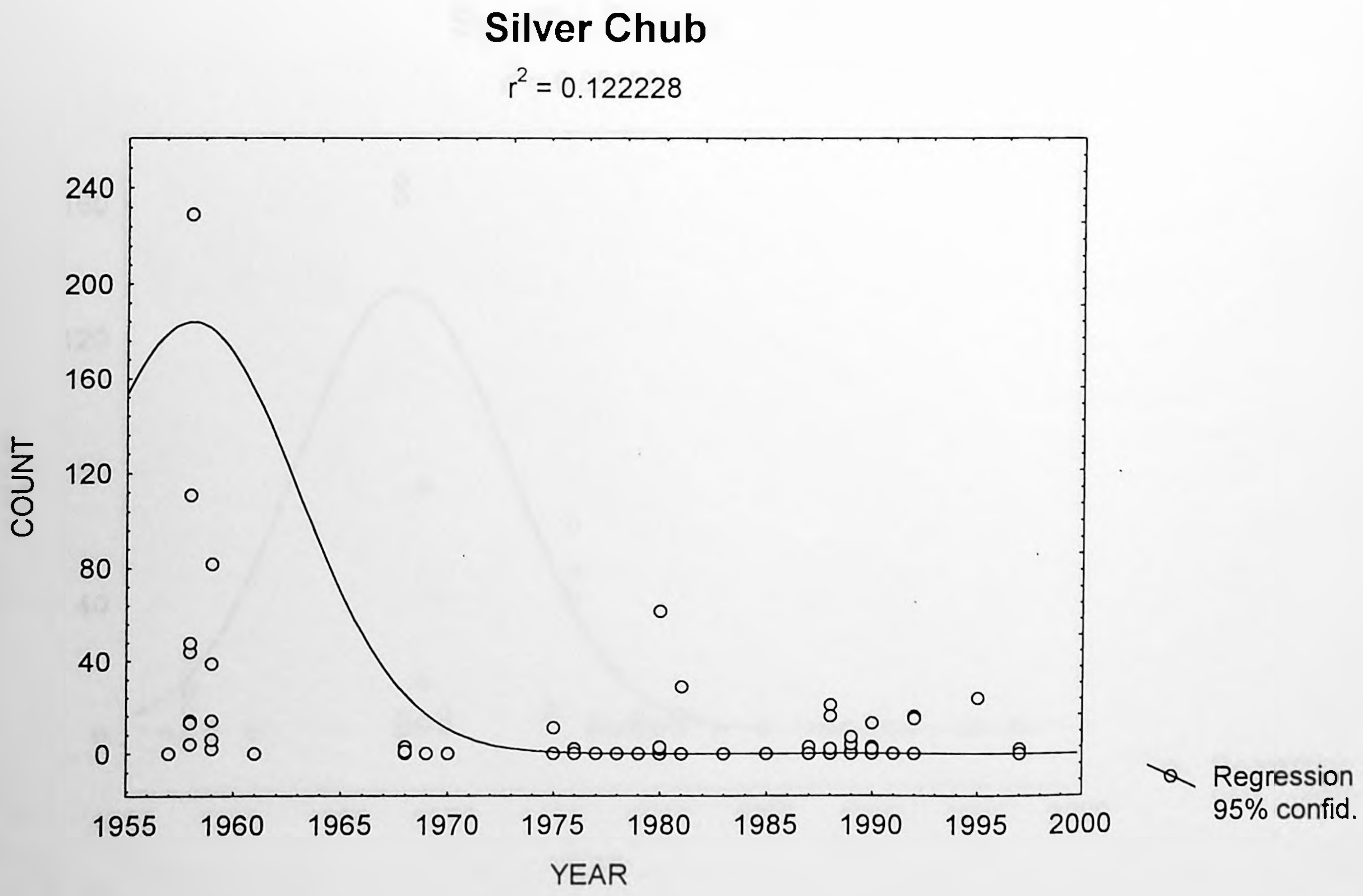

Fig. 104. Species showing a density peak along the upper river section.

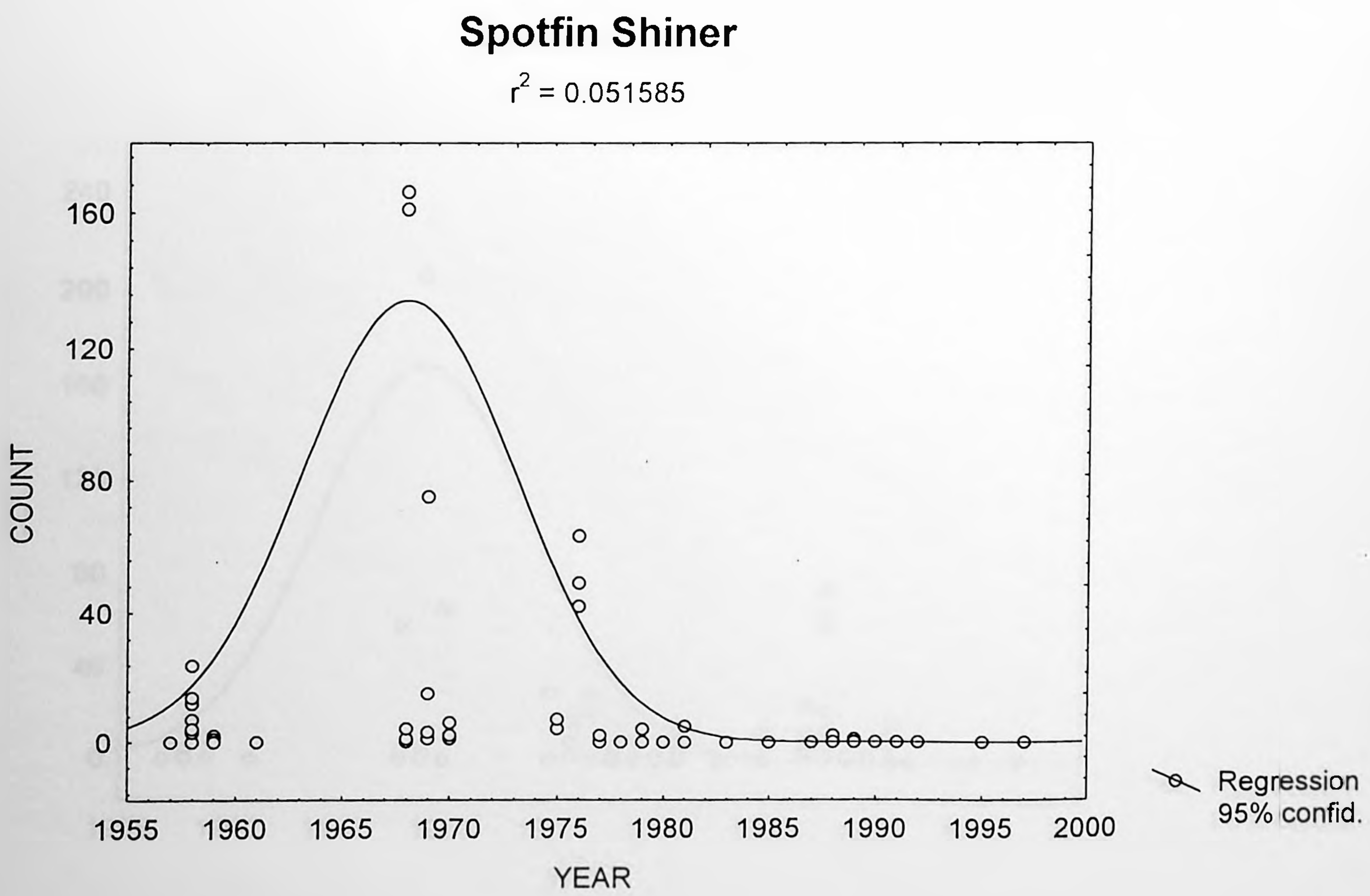

Fig. 105. Species showing a density peak along the upper river section.

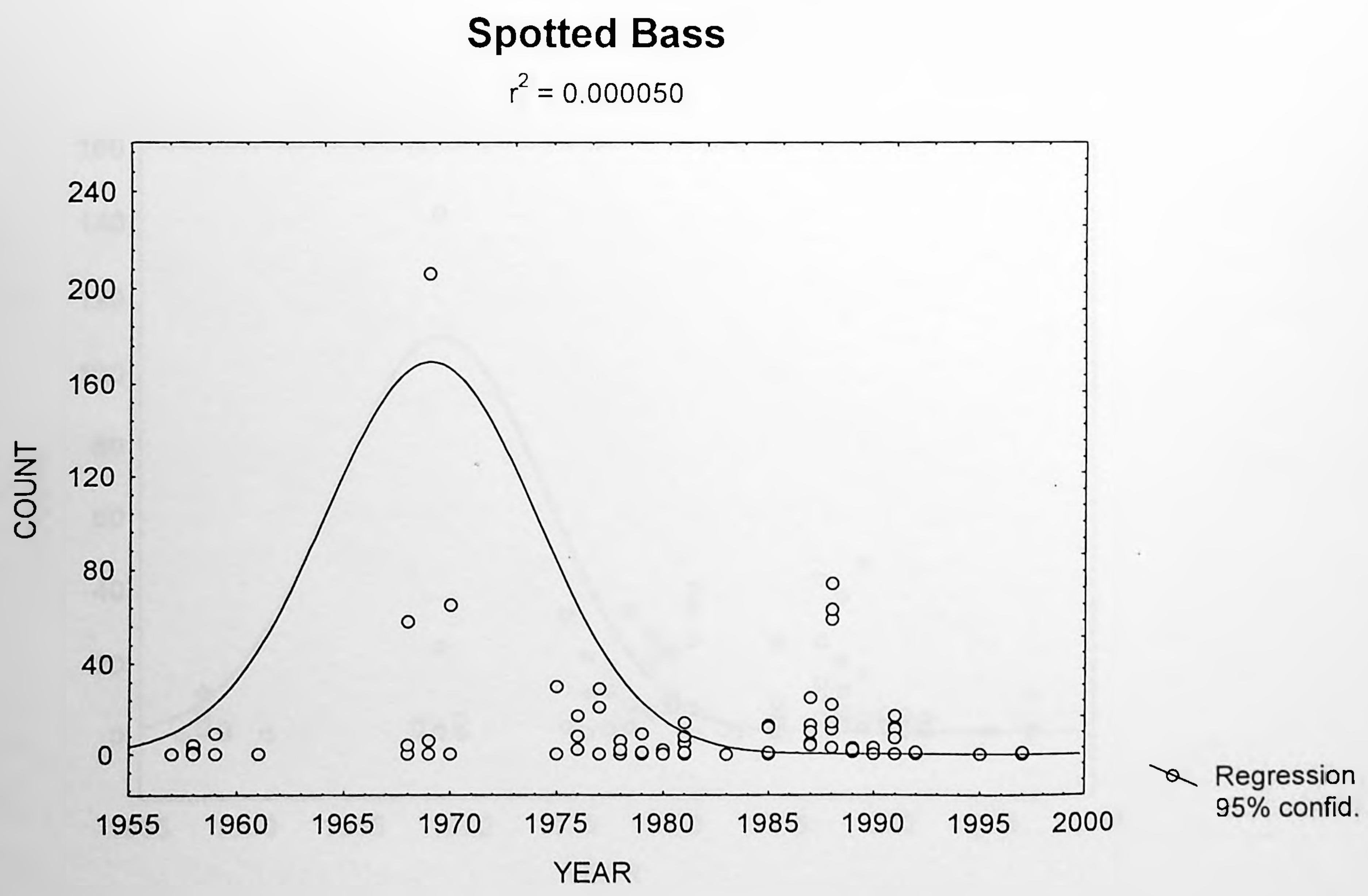

Fig. 106. Species showing a density peak along the upper river section.

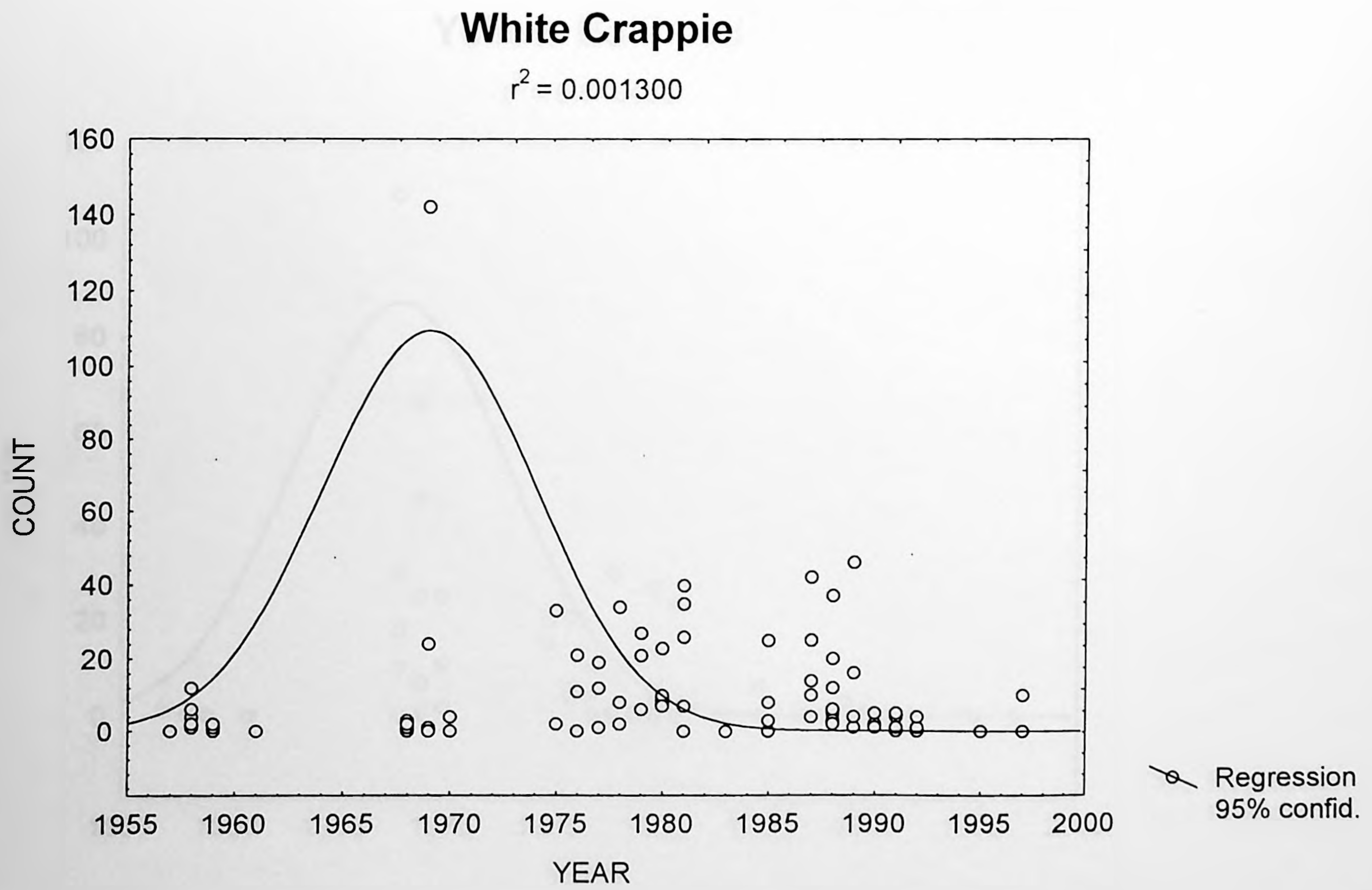

Fig. 107. Species showing a density peak along the upper river section.

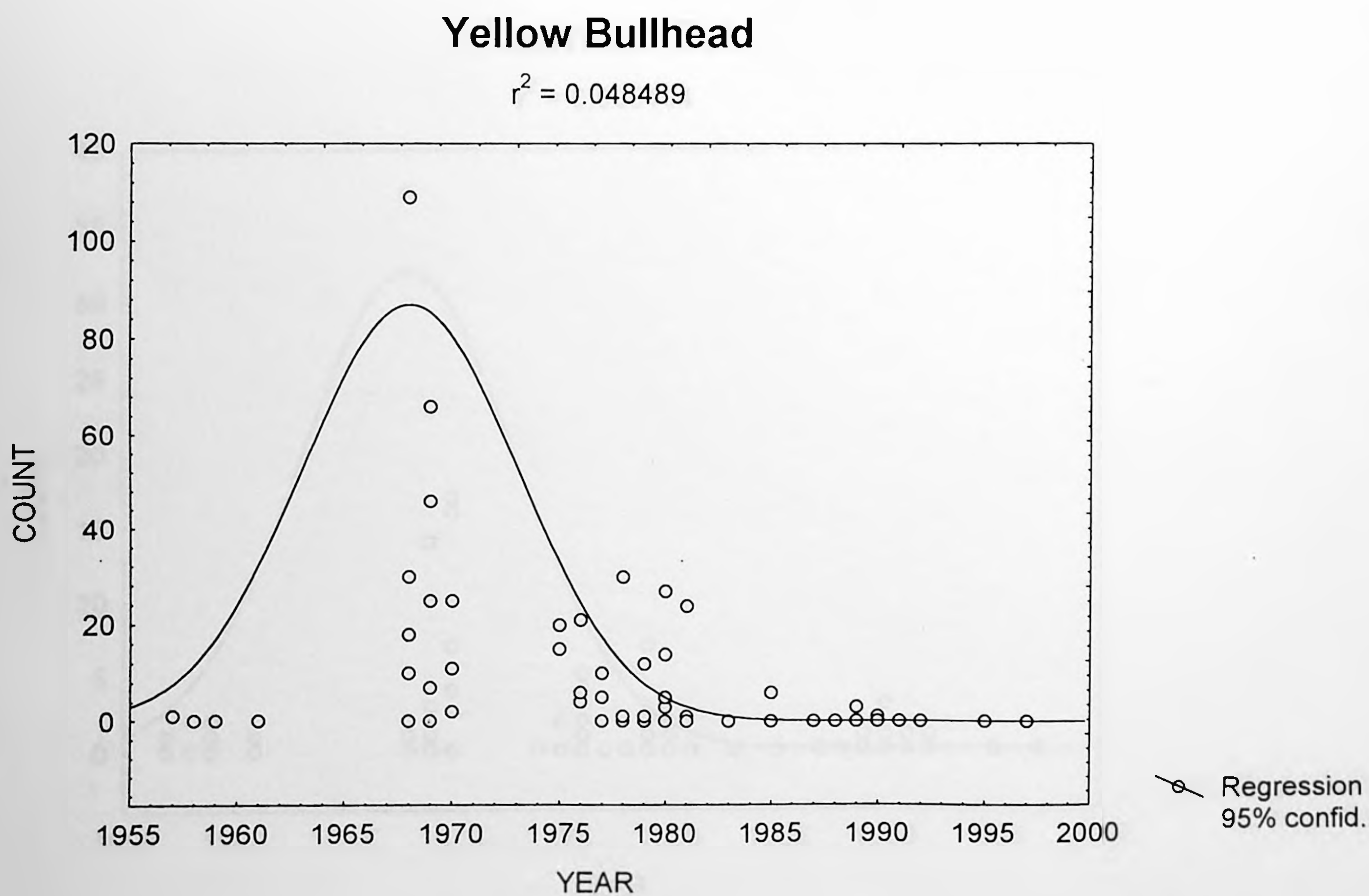

Fig. 108. Species showing a density peak along the upper river section.

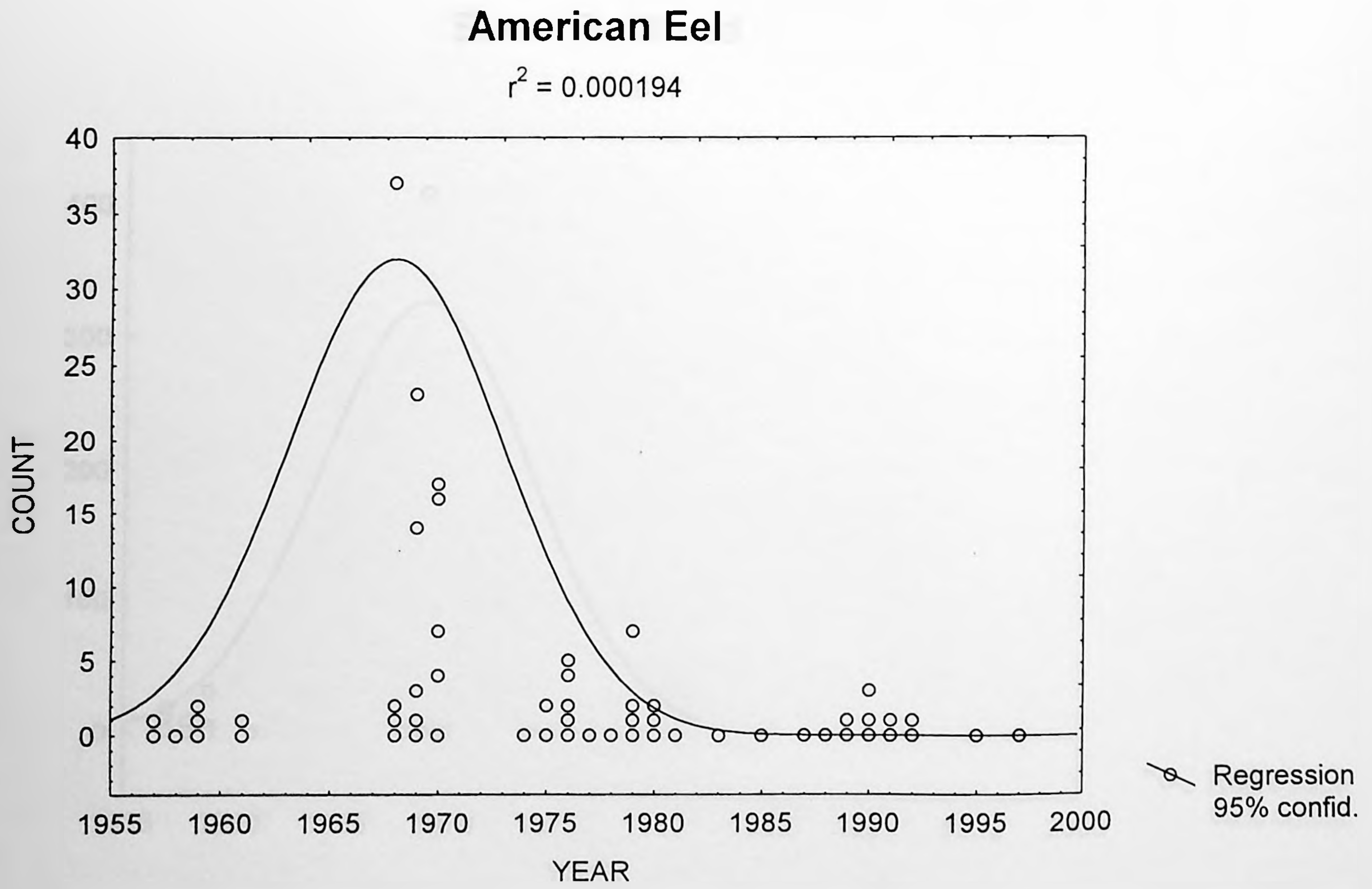

Fig. 109. Species showing a density peak along the middle river section.

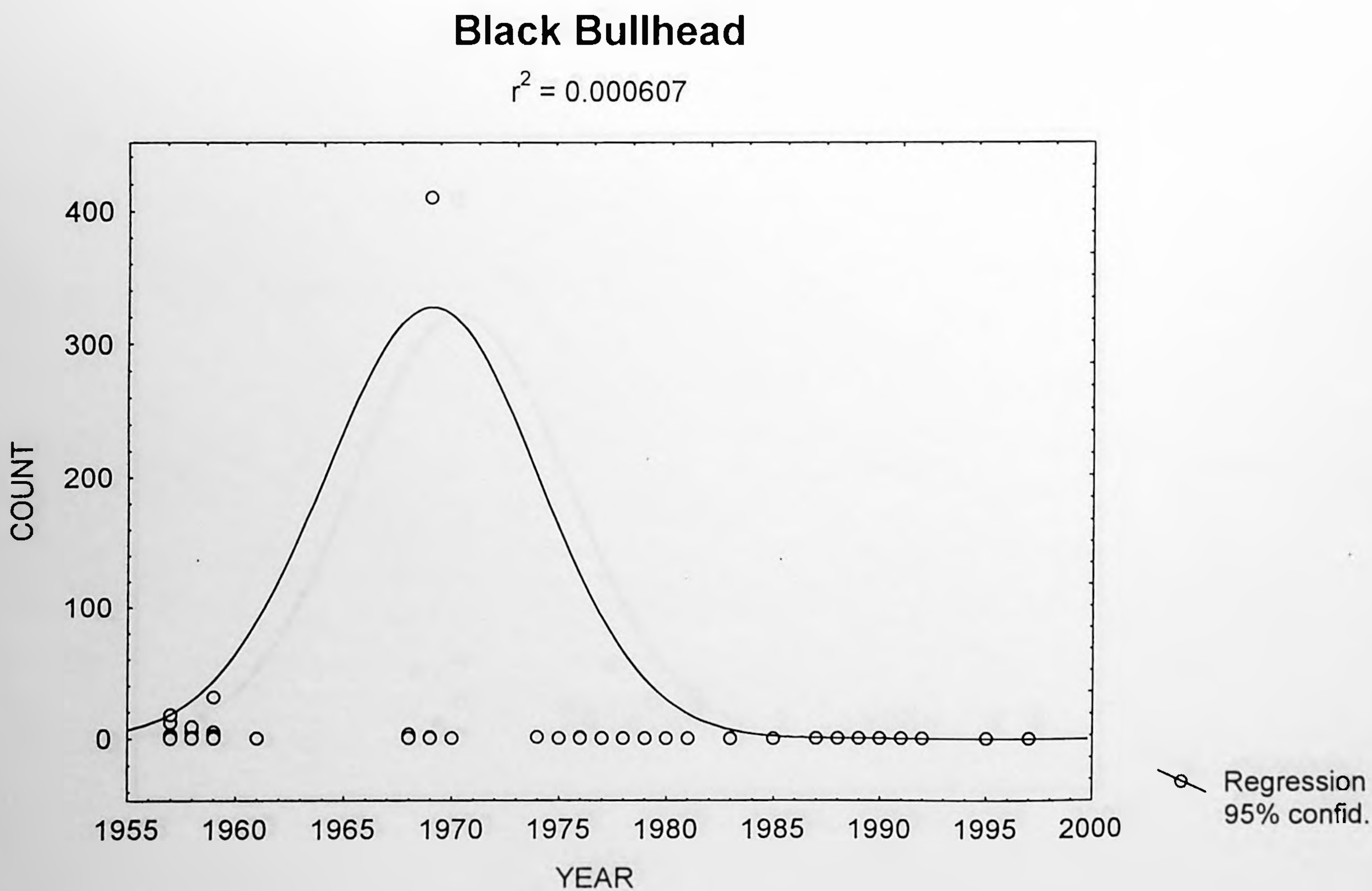

Fig. 110. Species showing a density peak along the middle river section.

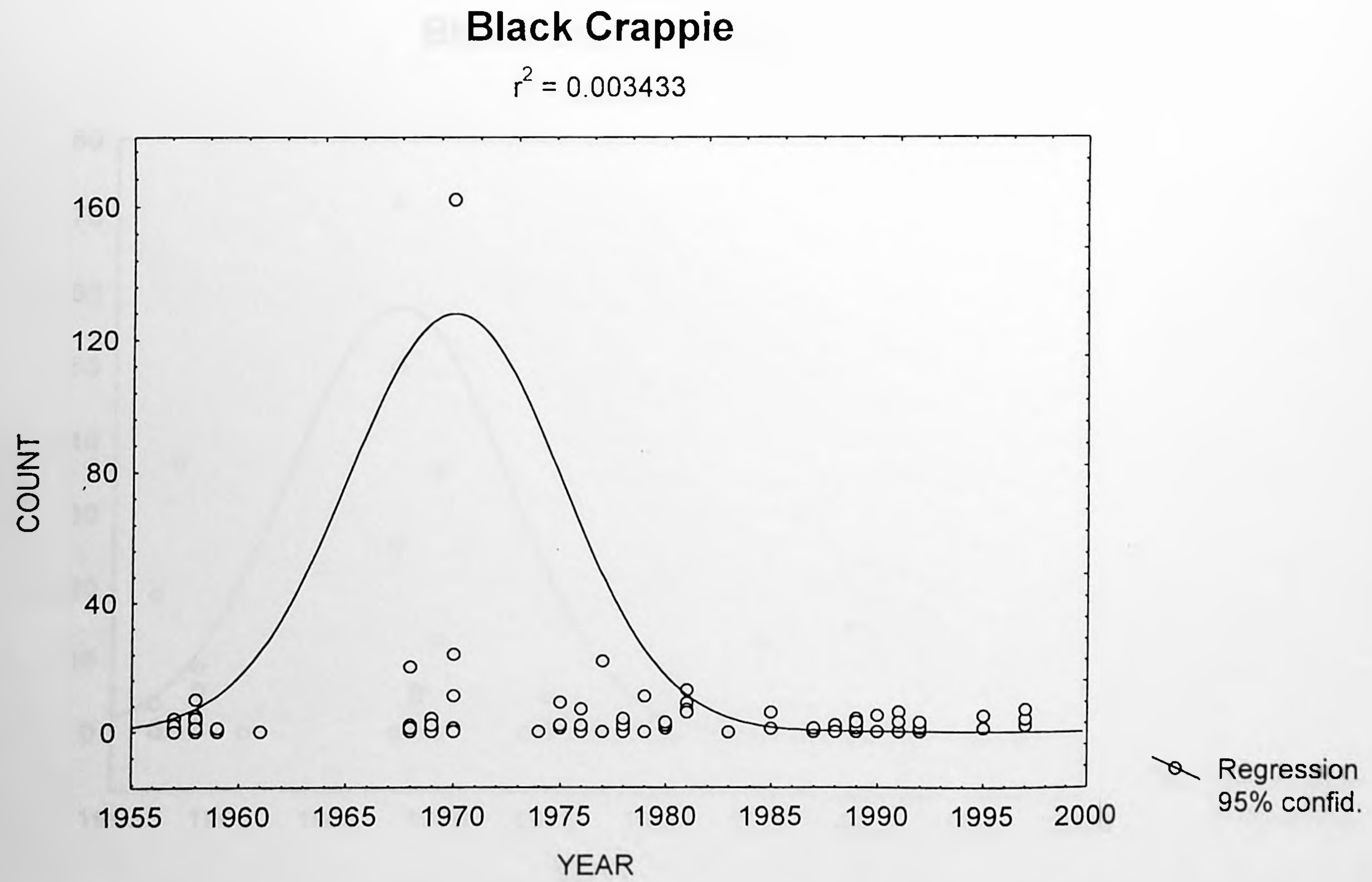

Fig. 111. Species showing a density peak along the middle river section.

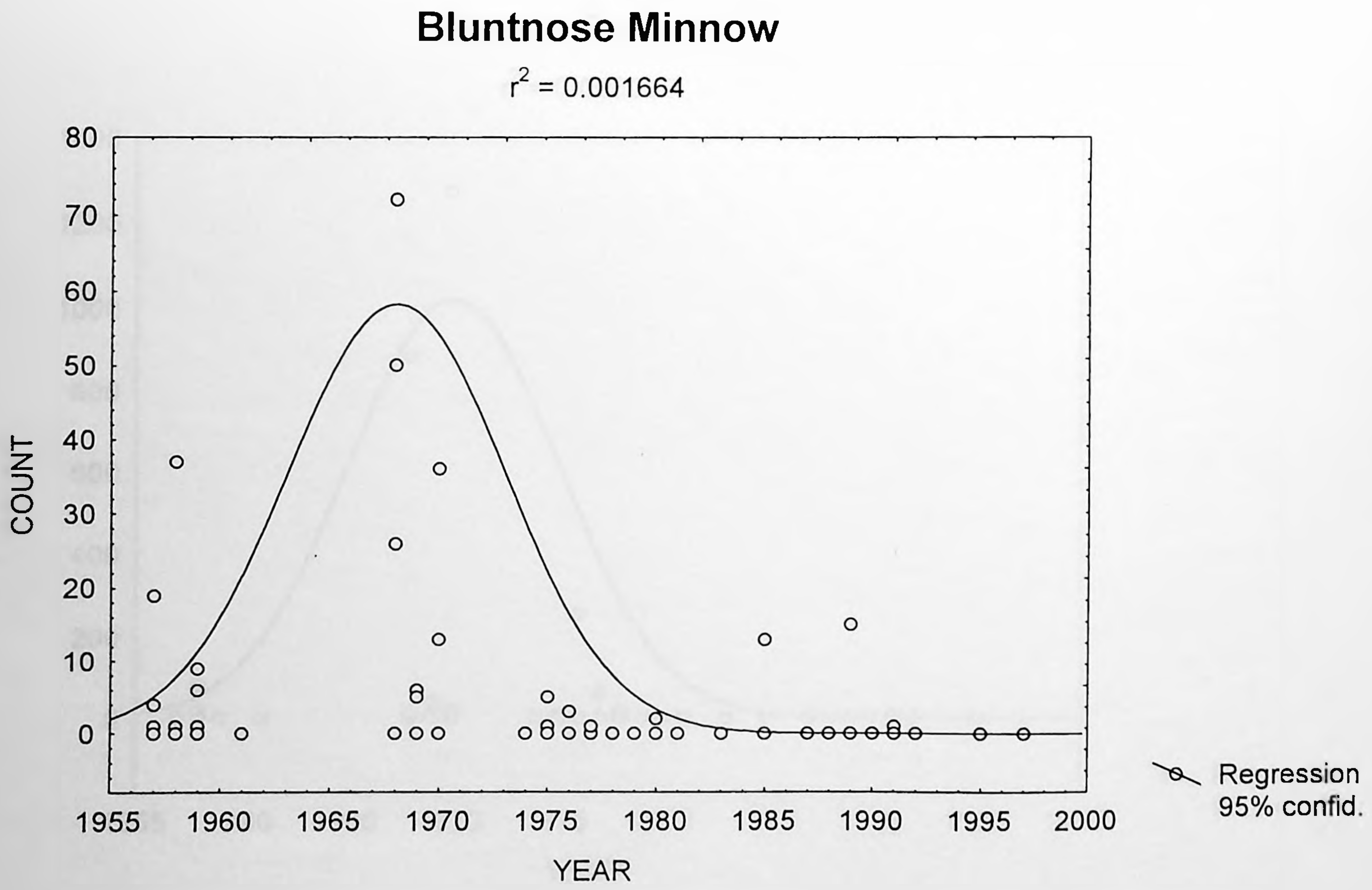

Fig. 112. Species showing a density peak along the middle river section.

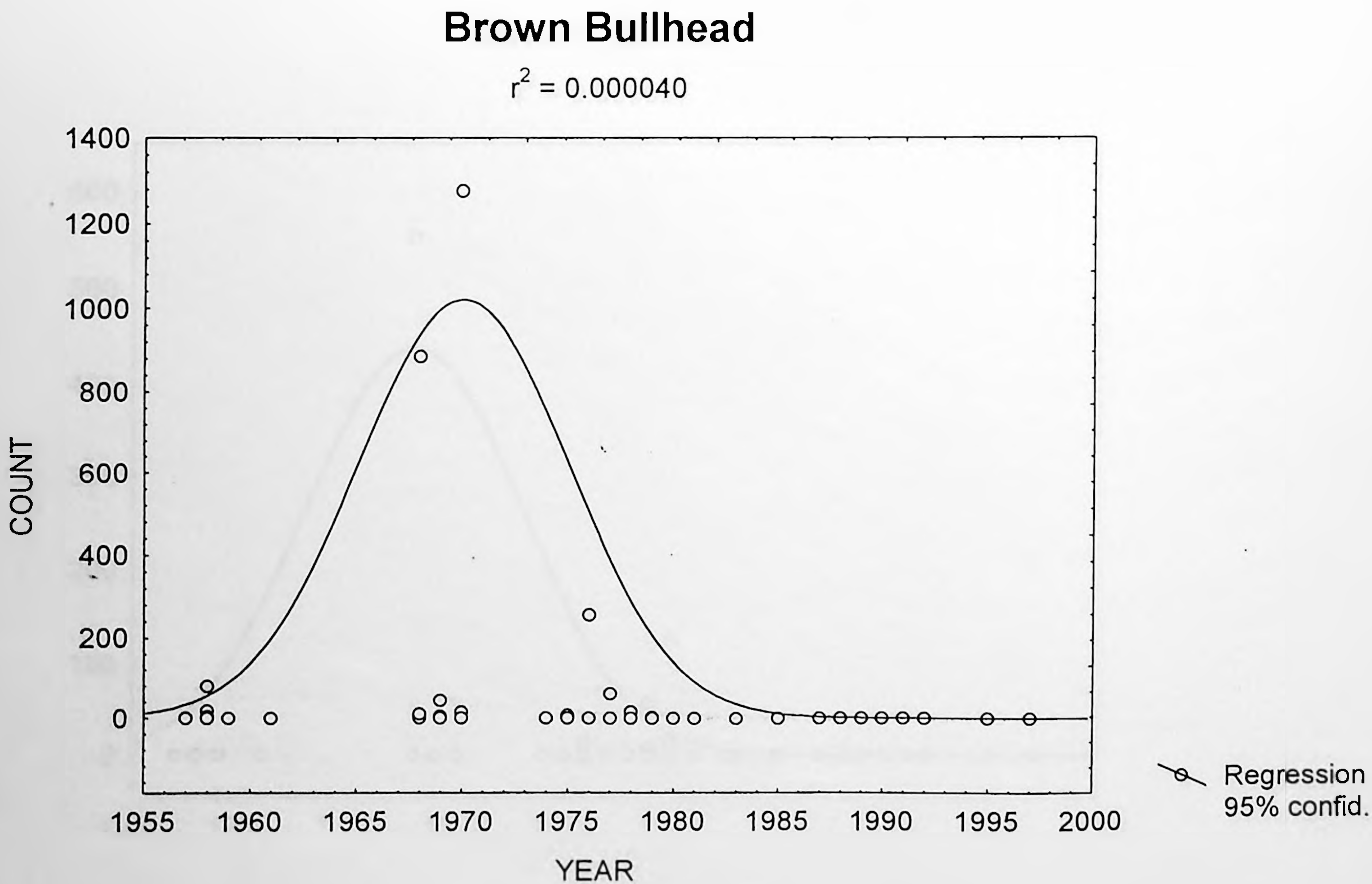

Fig. 113. Species showing a density peak along the middle river section.

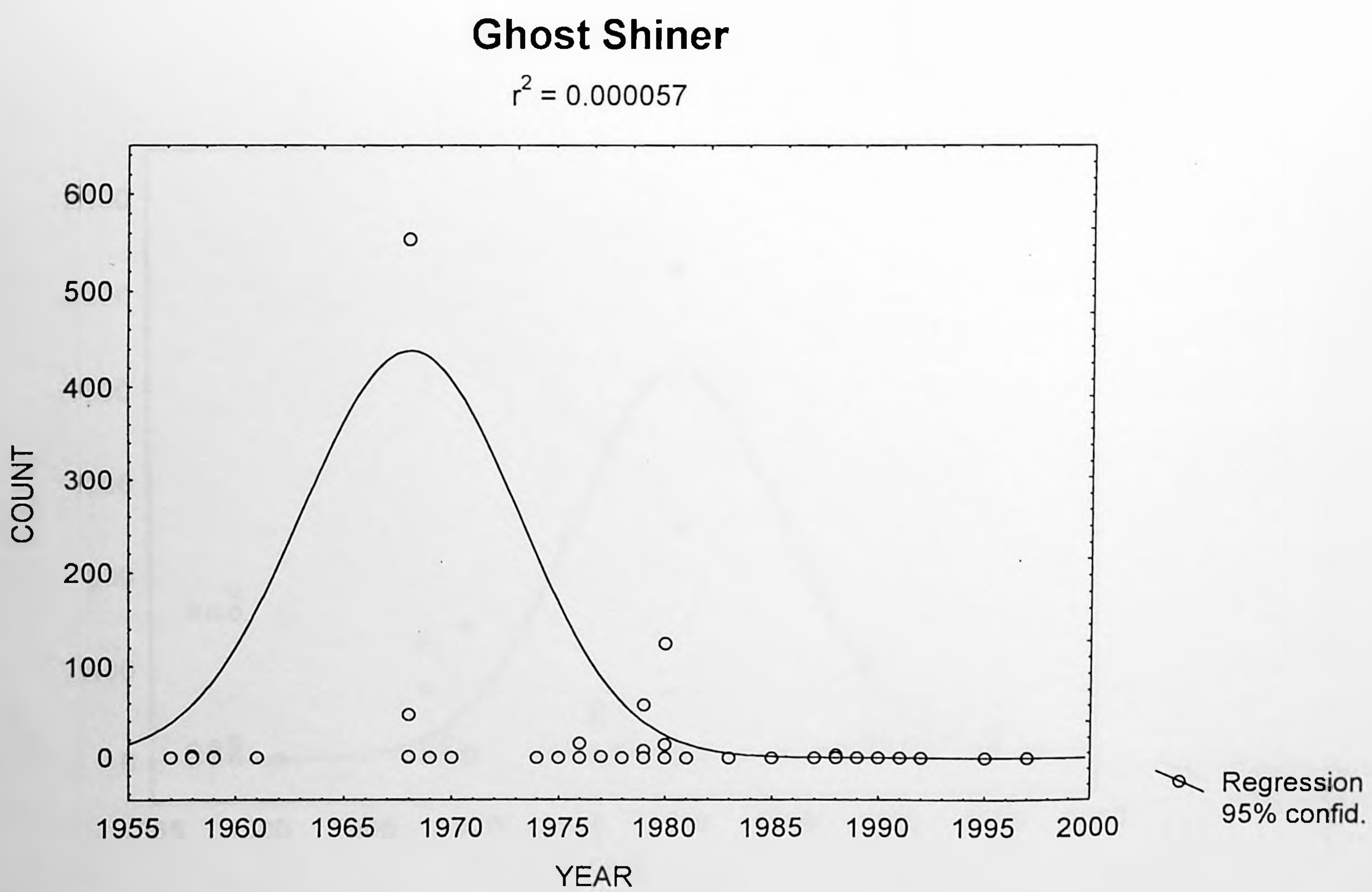

Fig. 114. Species showing a density peak along the middle river section.

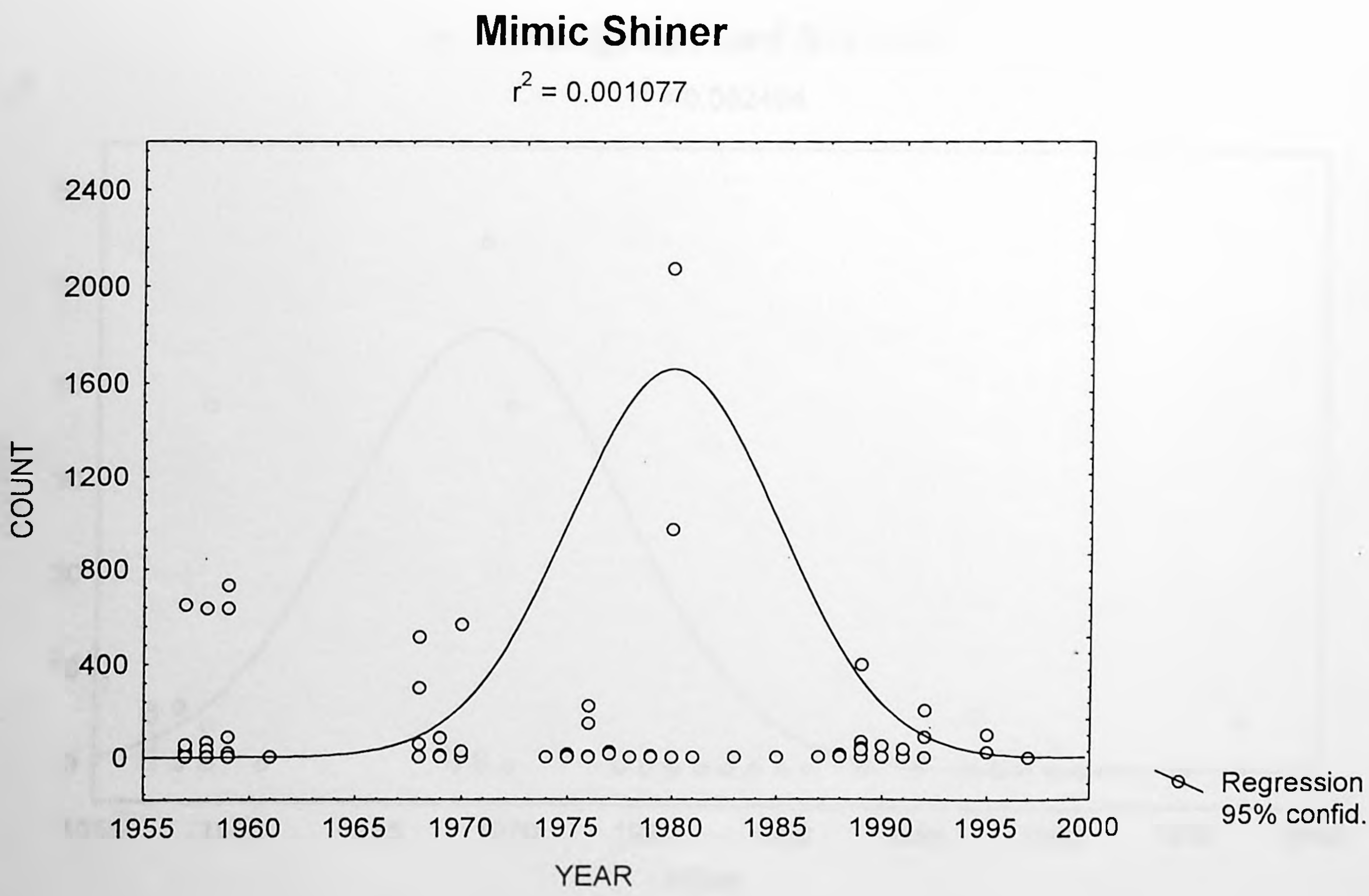

Fig. 115. Species showing a density peak along the middle river section.

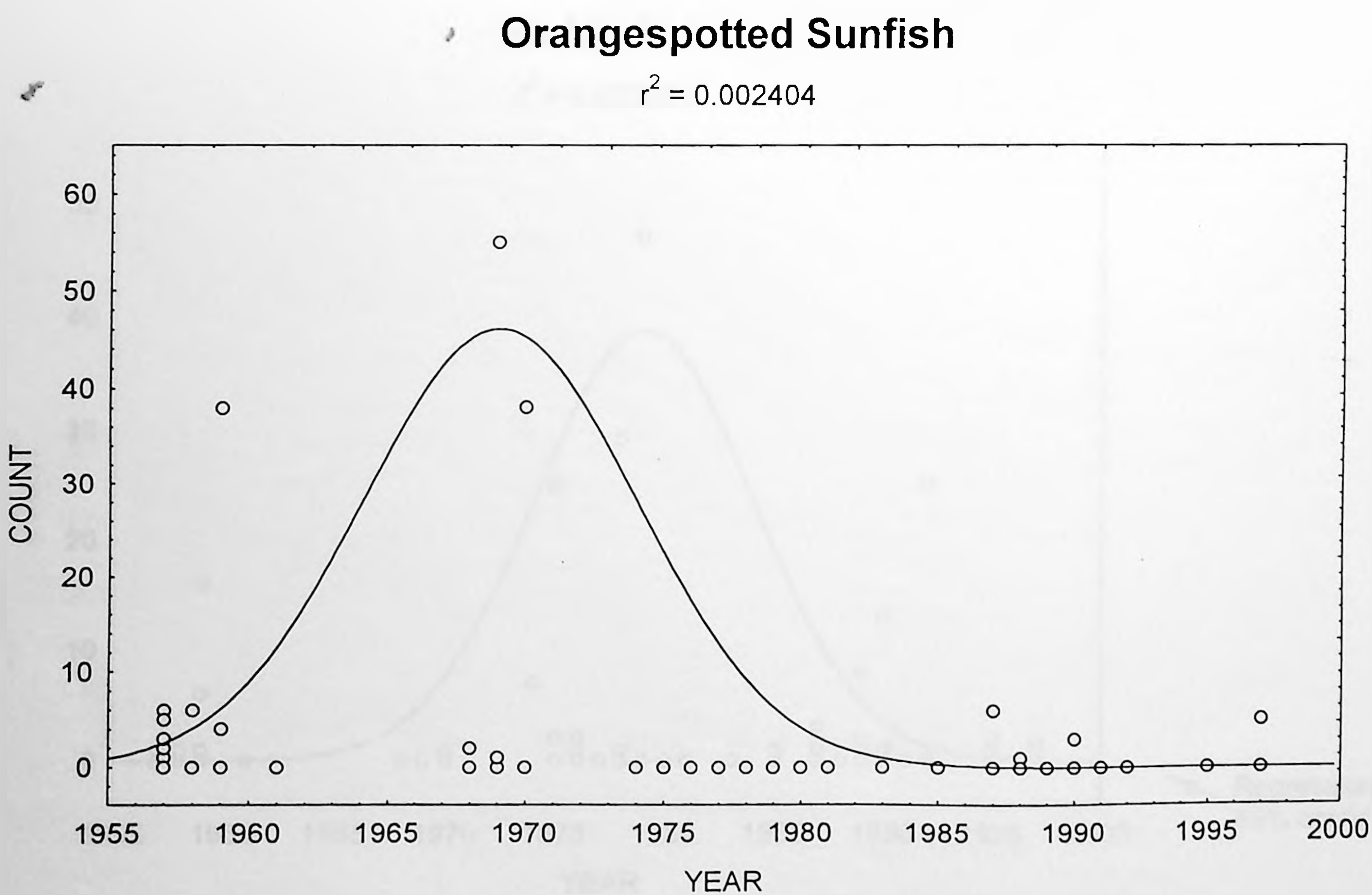

Fig. 116. Species showing a density peak along the middle river section.

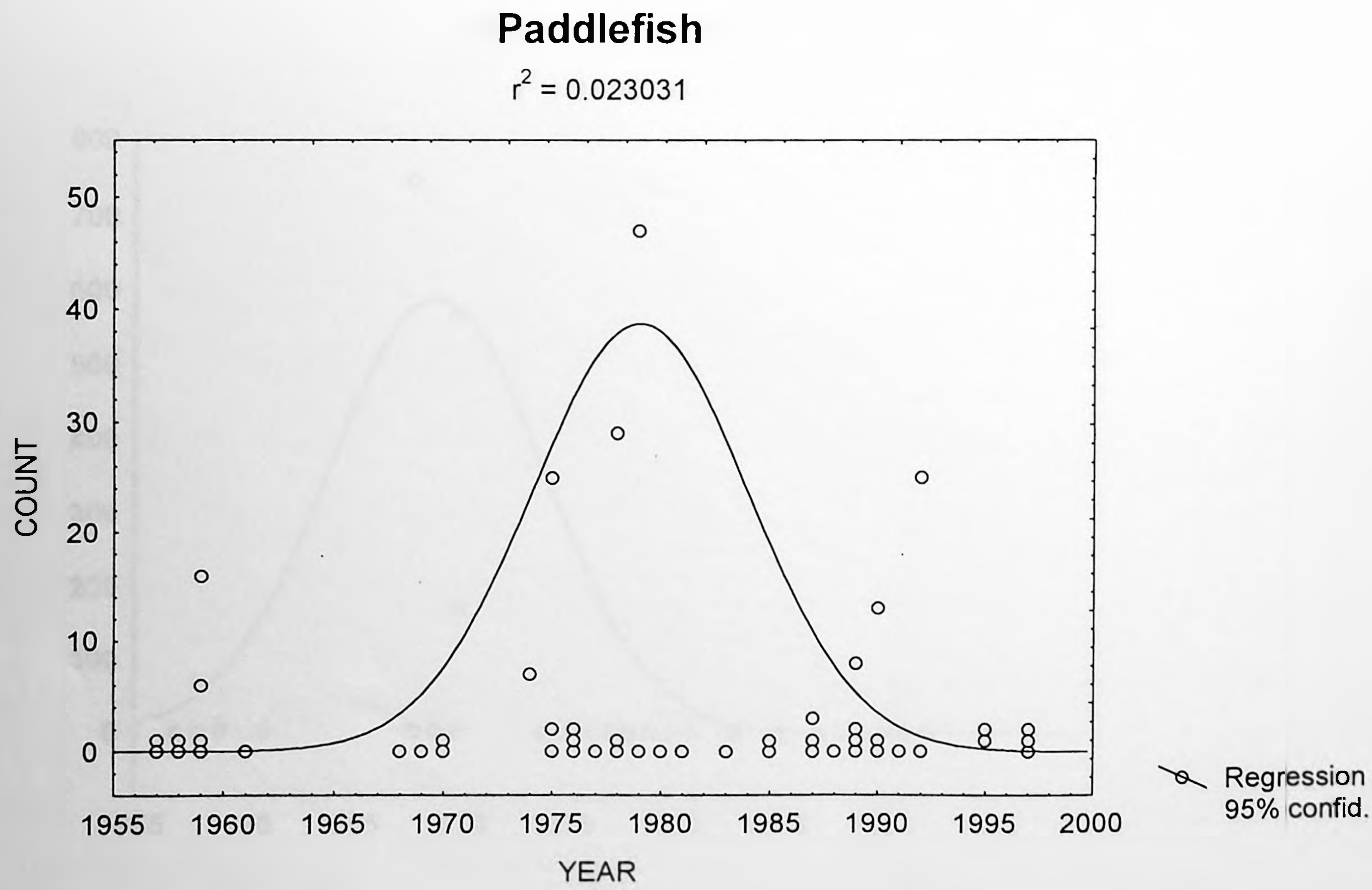

Fig. 117. Species showing a density peak along the middle river section.

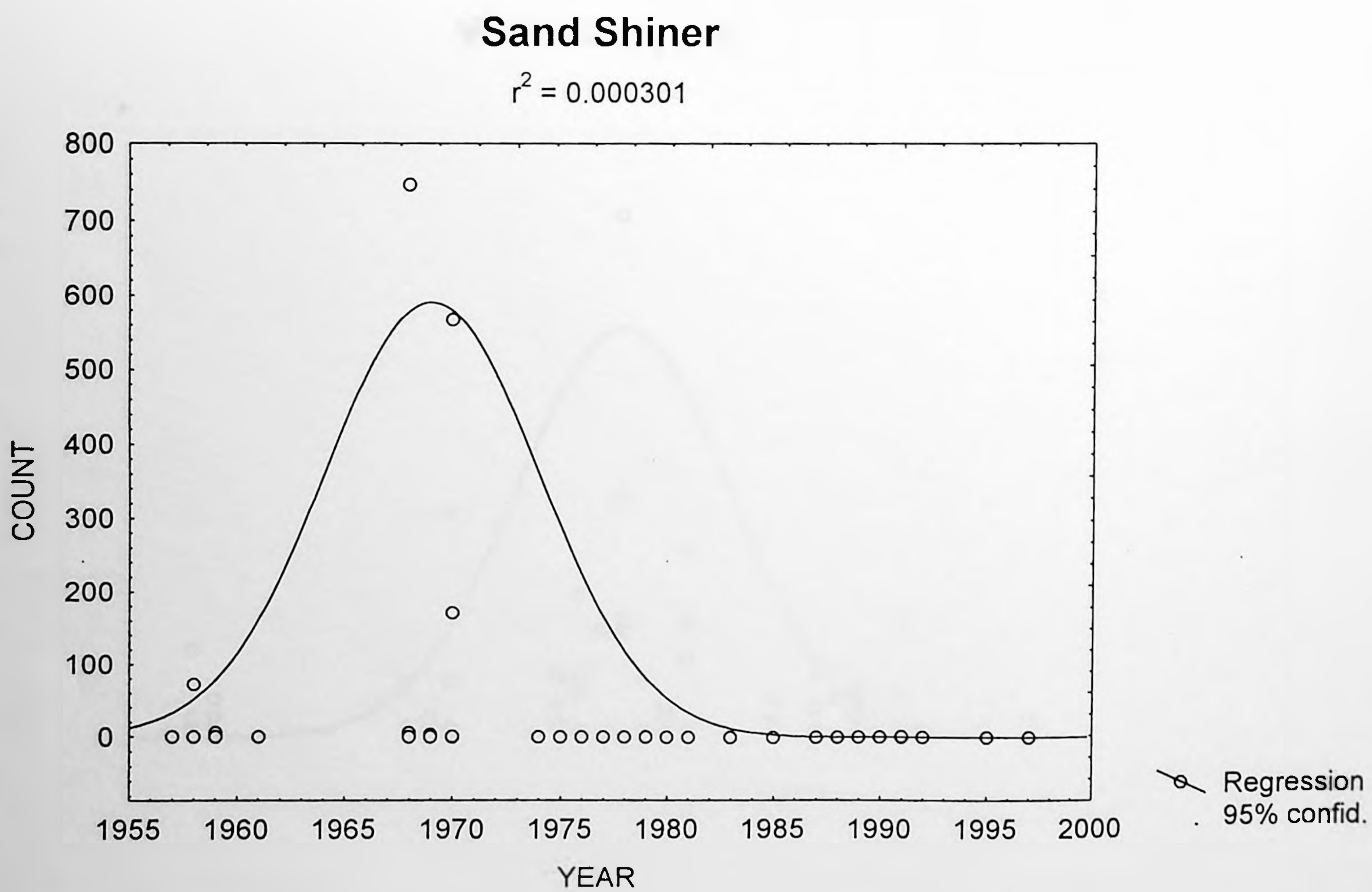

Fig. 118. Species showing a density peak along the middle river section.

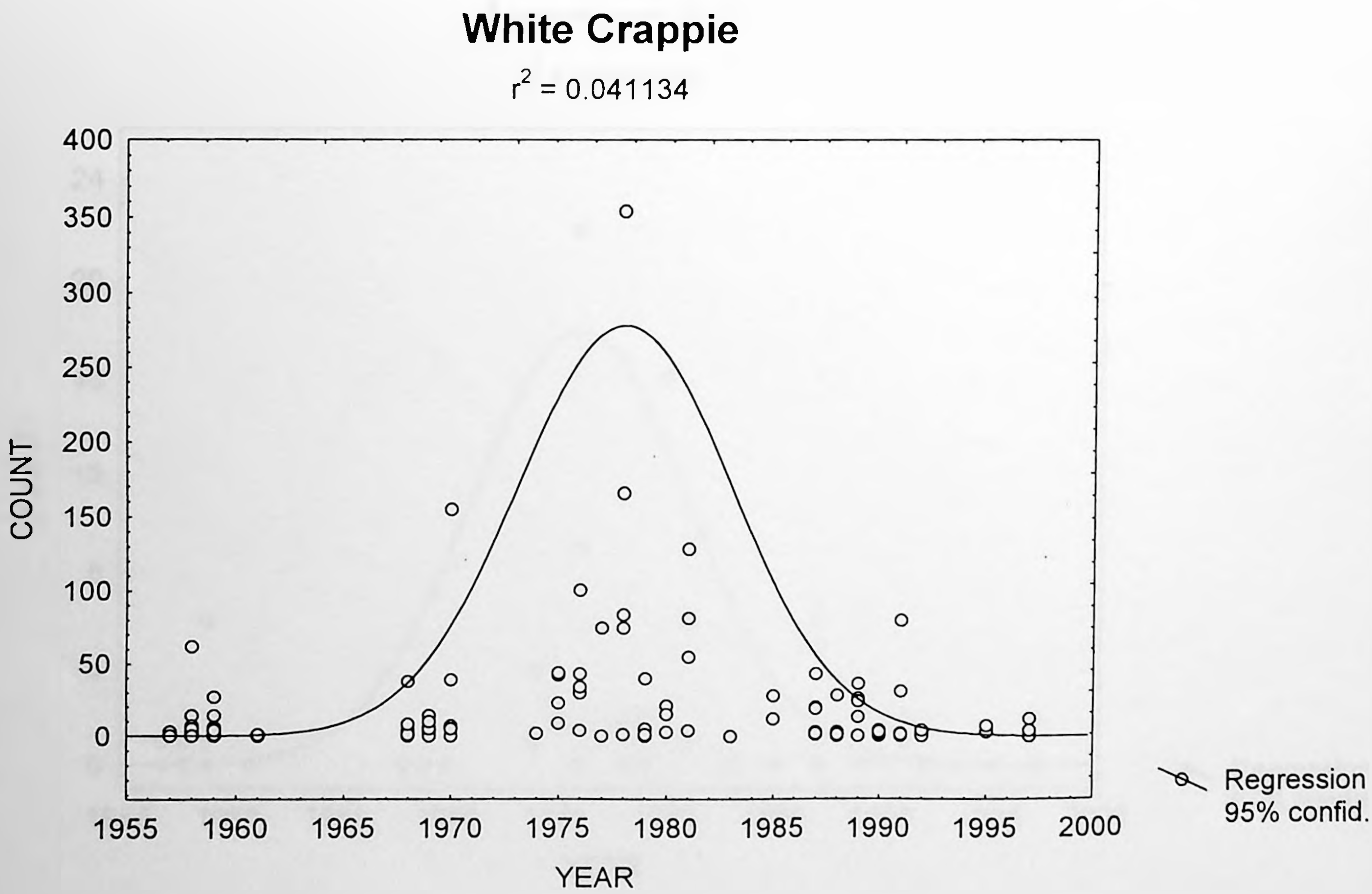

Fig. 119. Species showing a density peak along the middle river section.

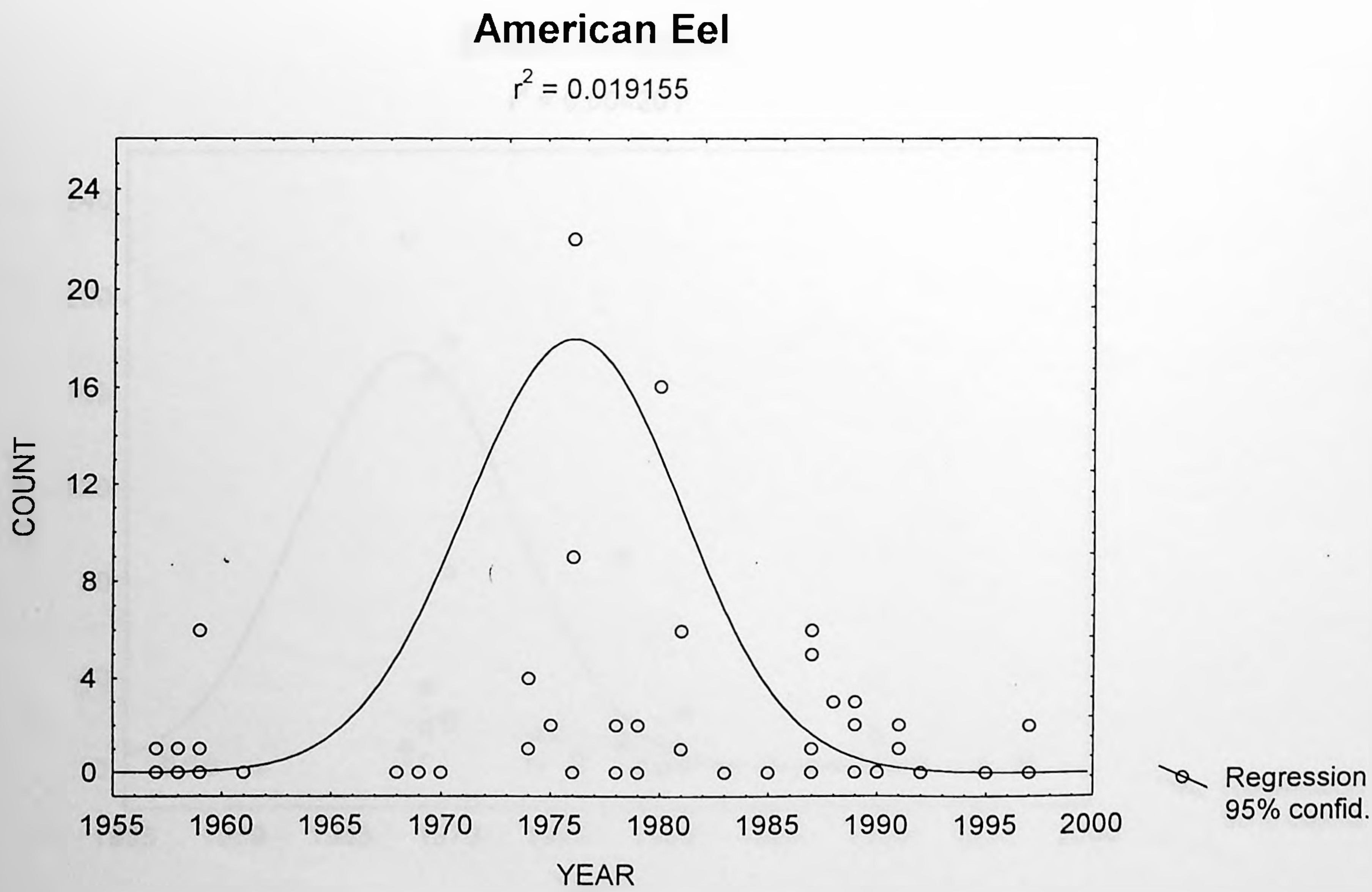

Fig. 120. Species showing a density peak along the lower river section.

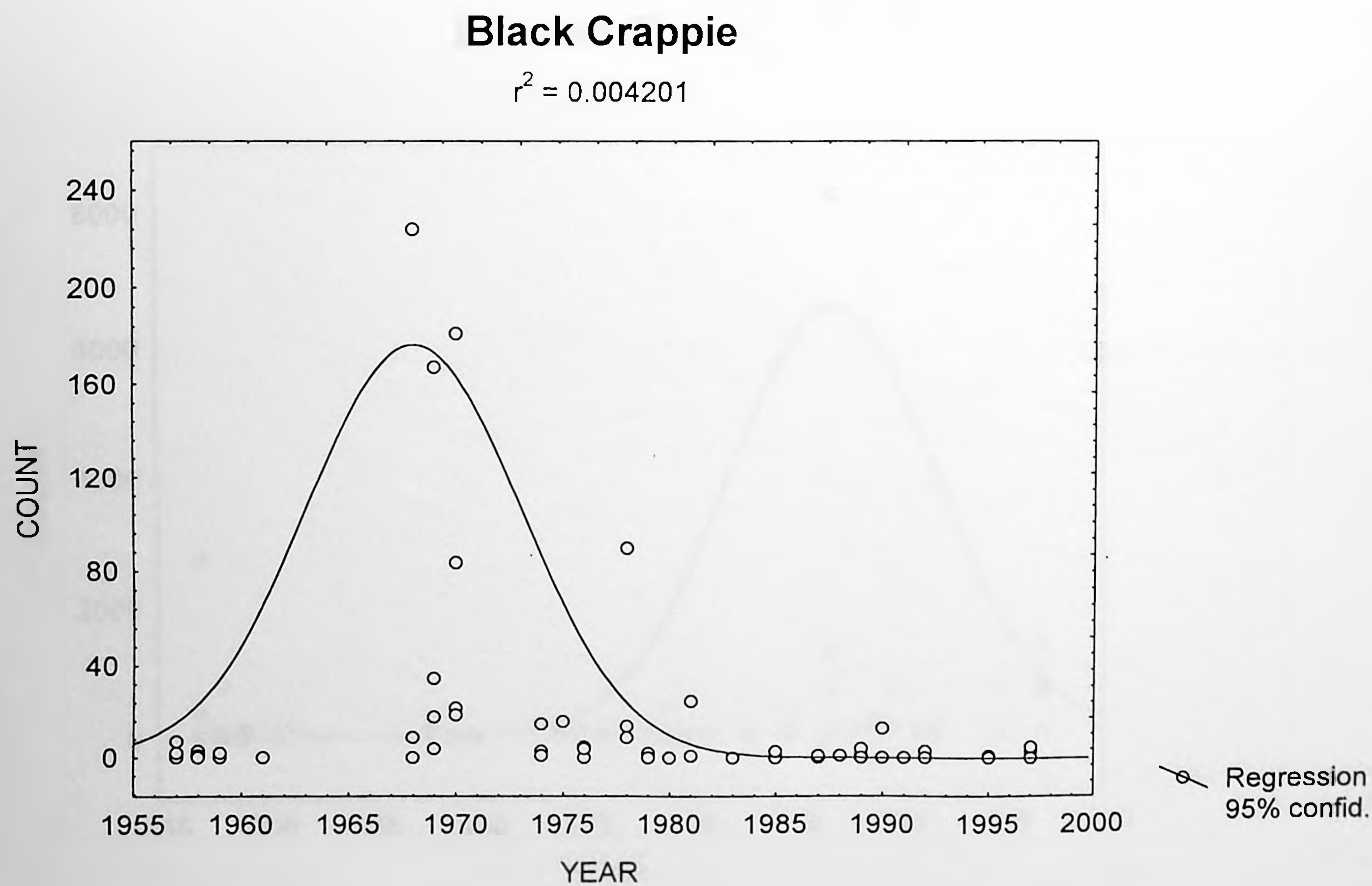

Fig. 121. Species showing a density peak along the lower river section.

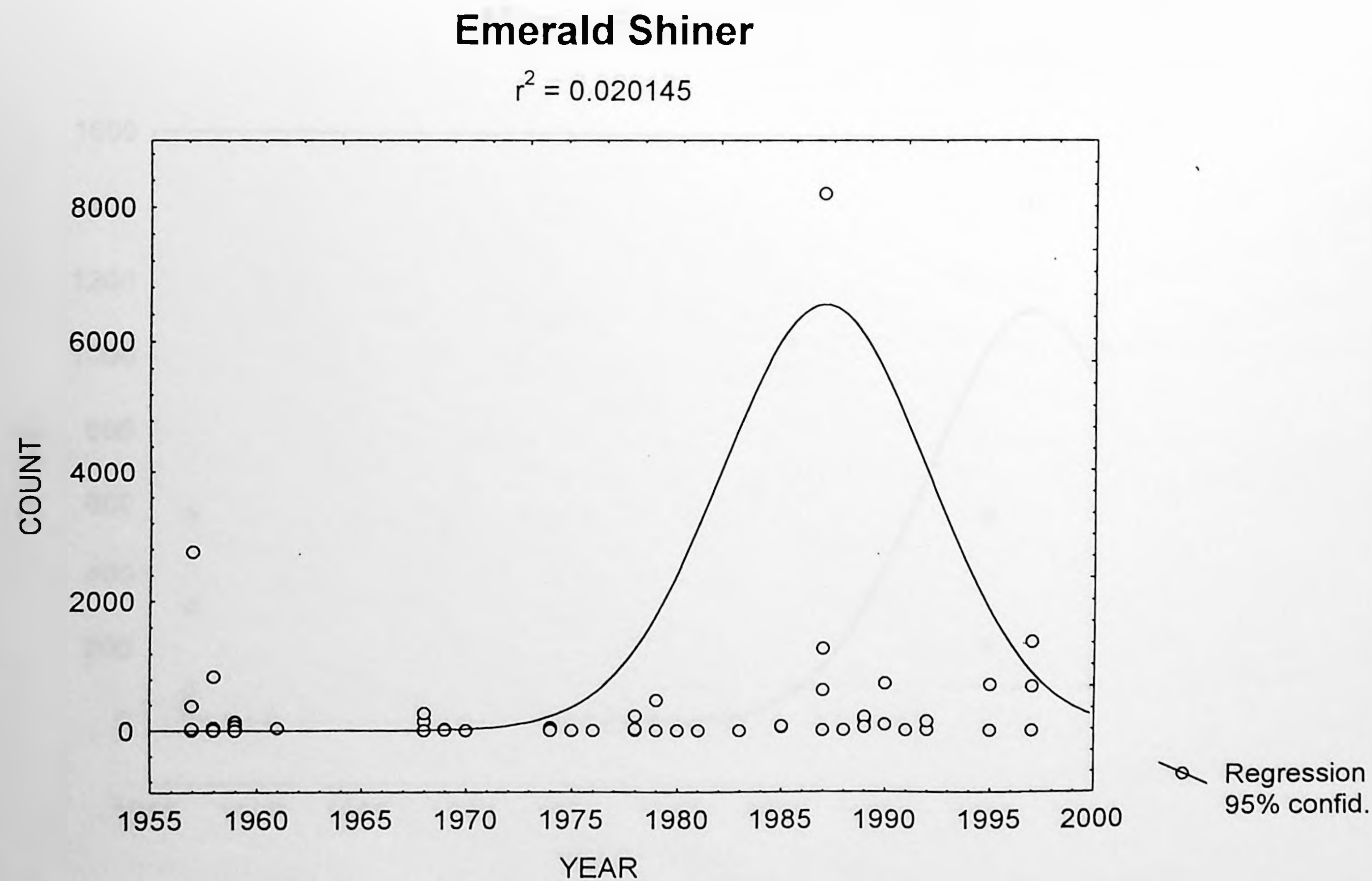

Fig. 122. Species showing a density peak along the lower river section.

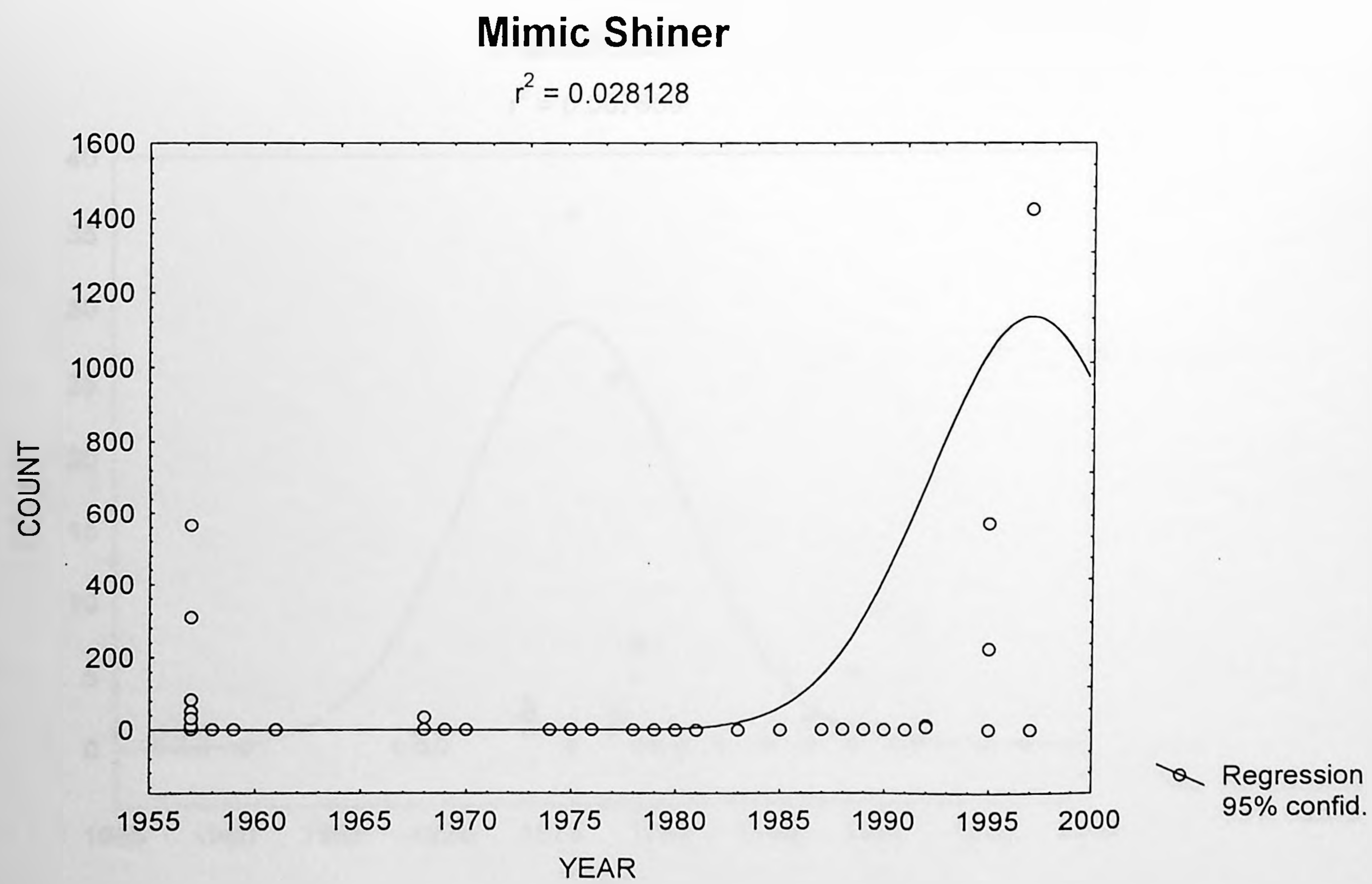

Fig. 123. Species showing a density peak along the lower river section.

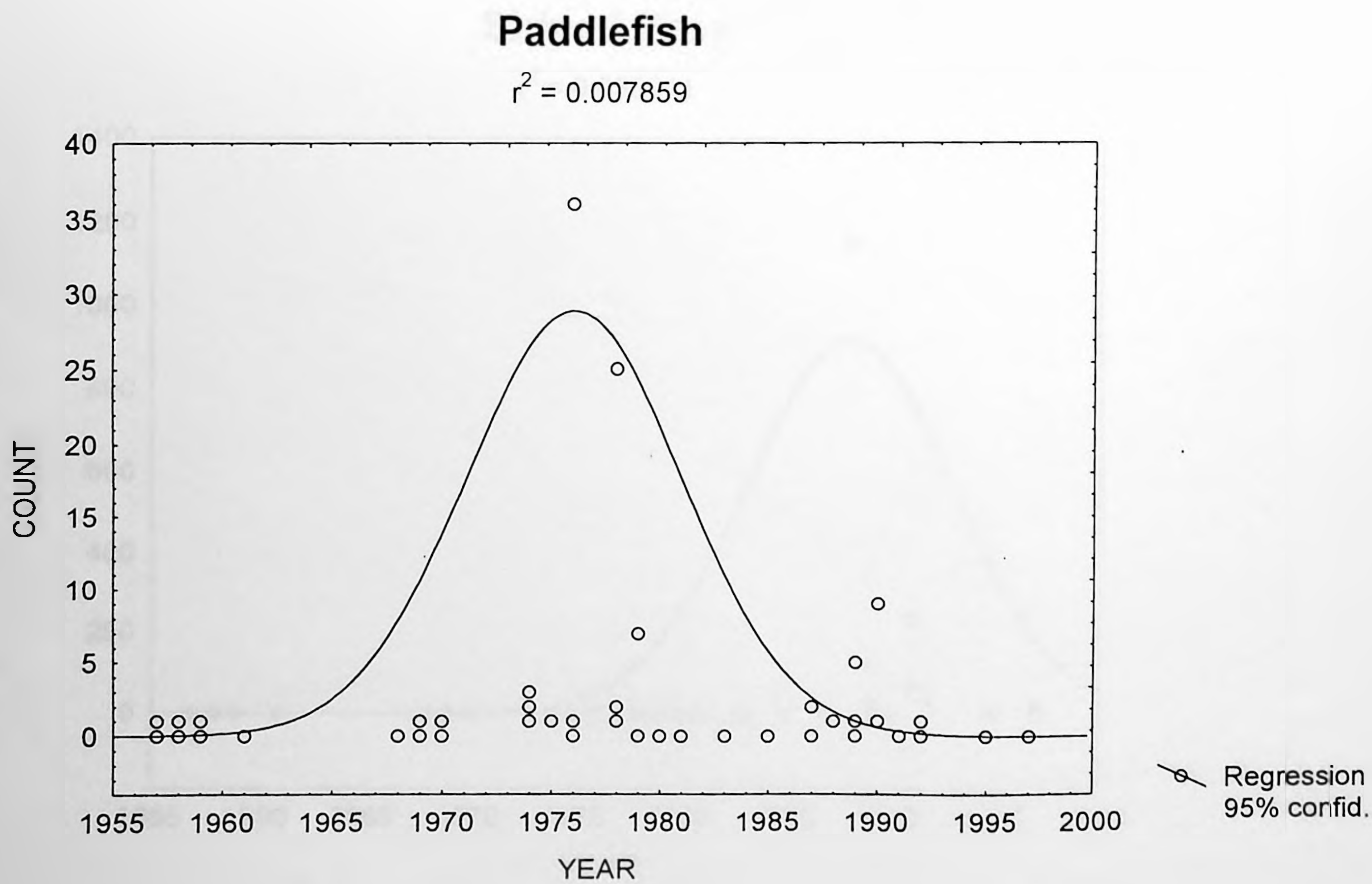

Fig. 124. Species showing a density peak along the lower river section.

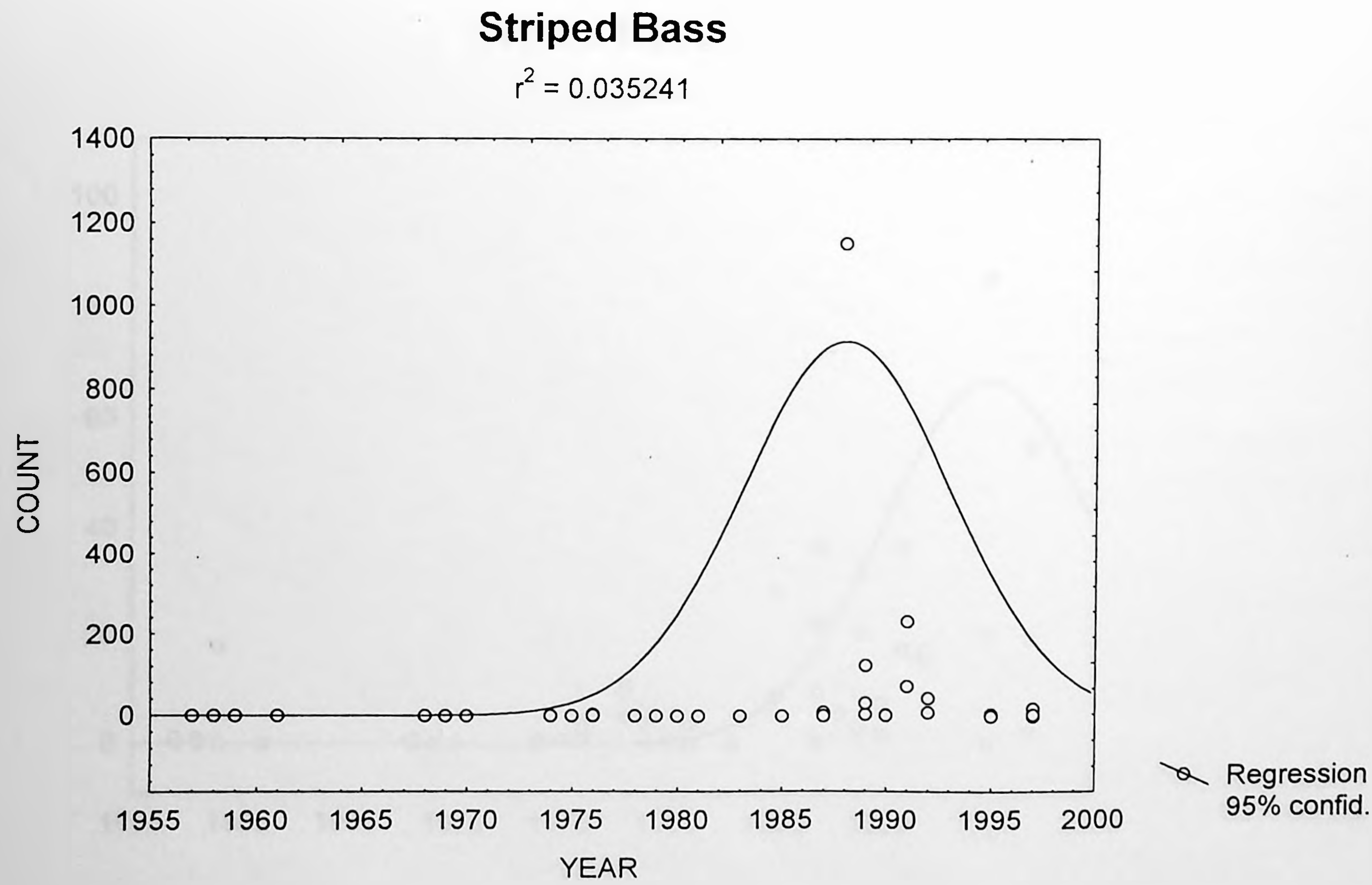

Fig. 125. Species showing a density peak along the lower river section.

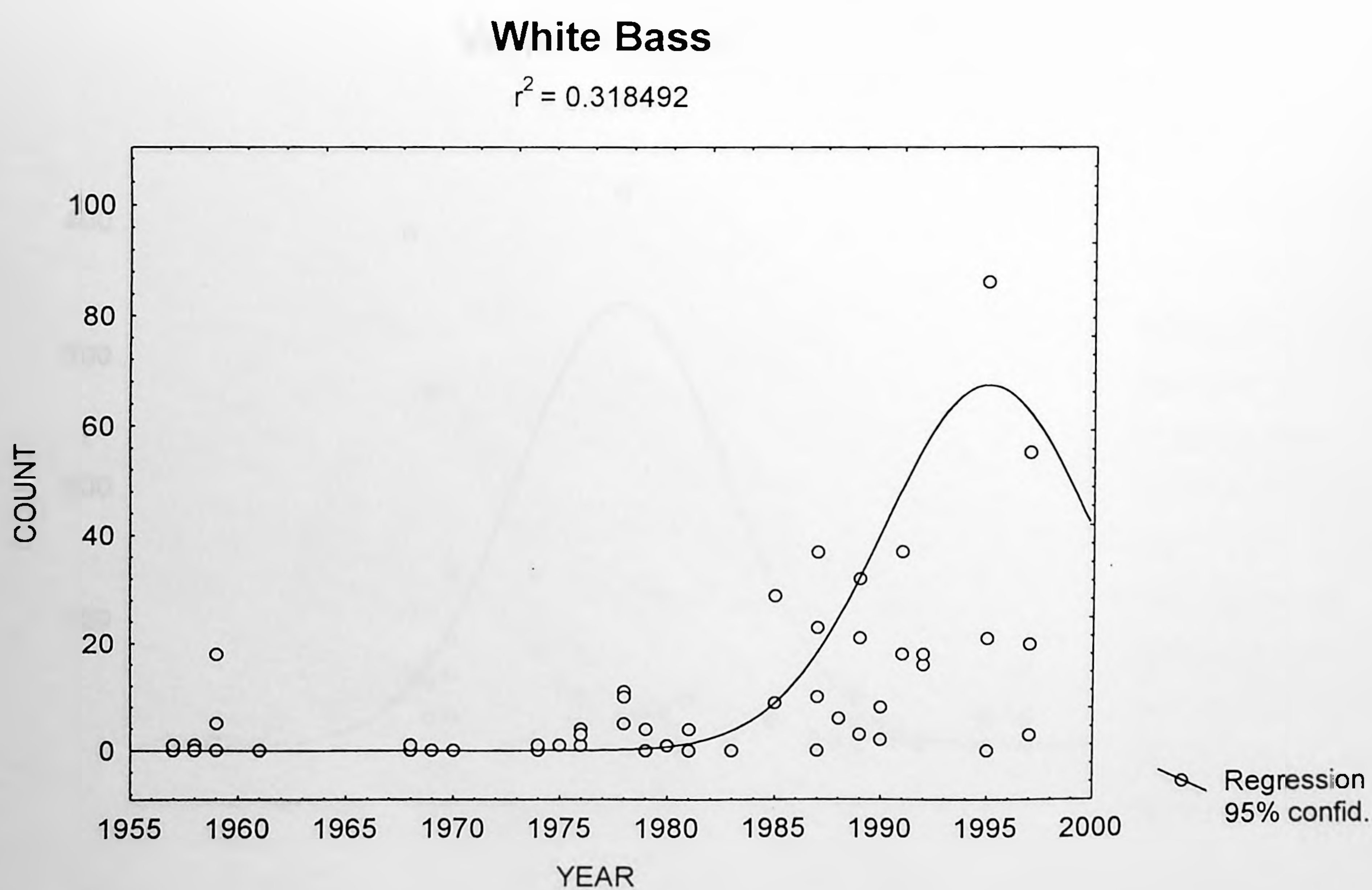

Fig. 126. Species showing a density peak along the lower river section.

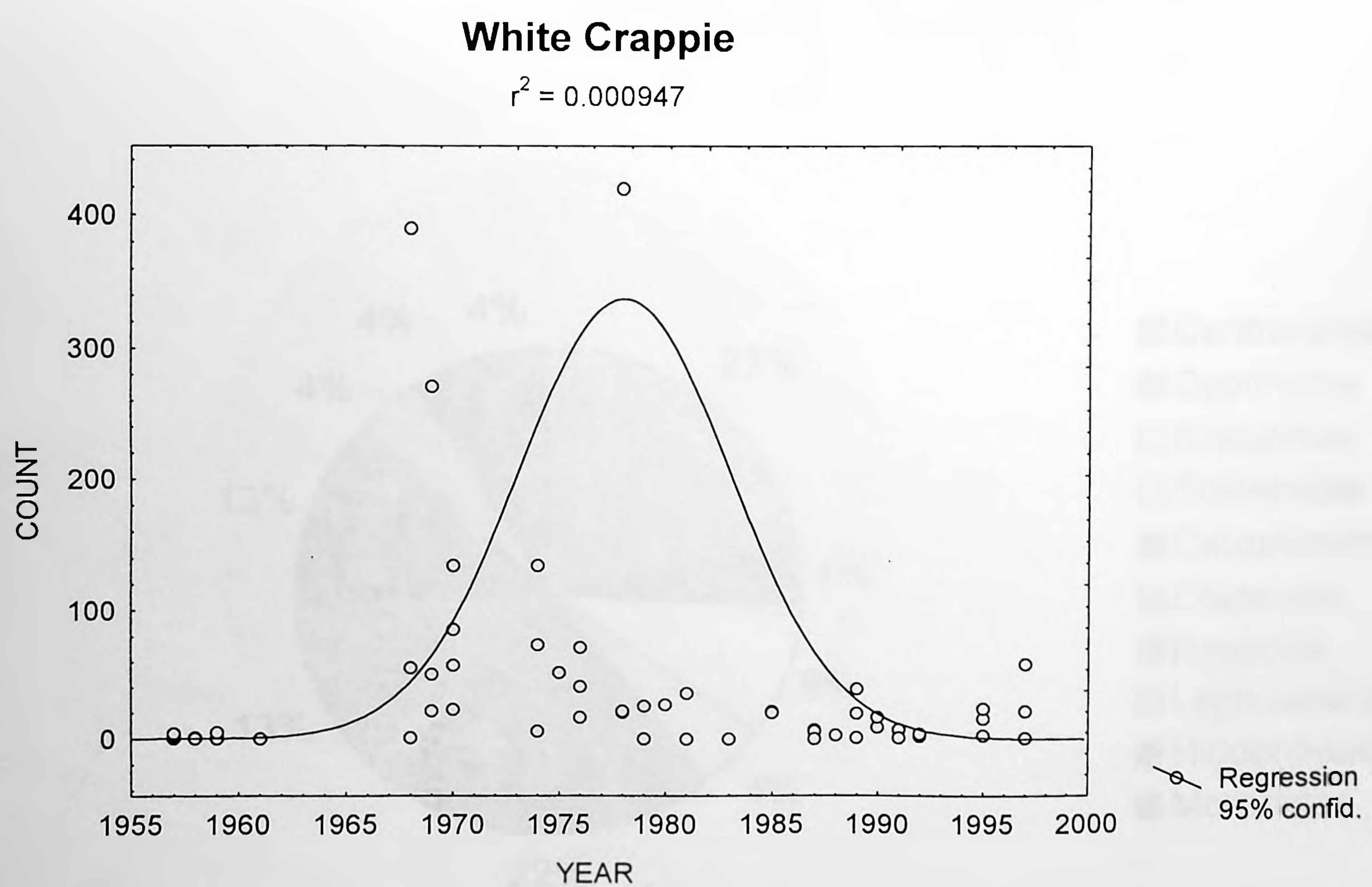

Fig. 127. Species showing a density peak along the lower river section.

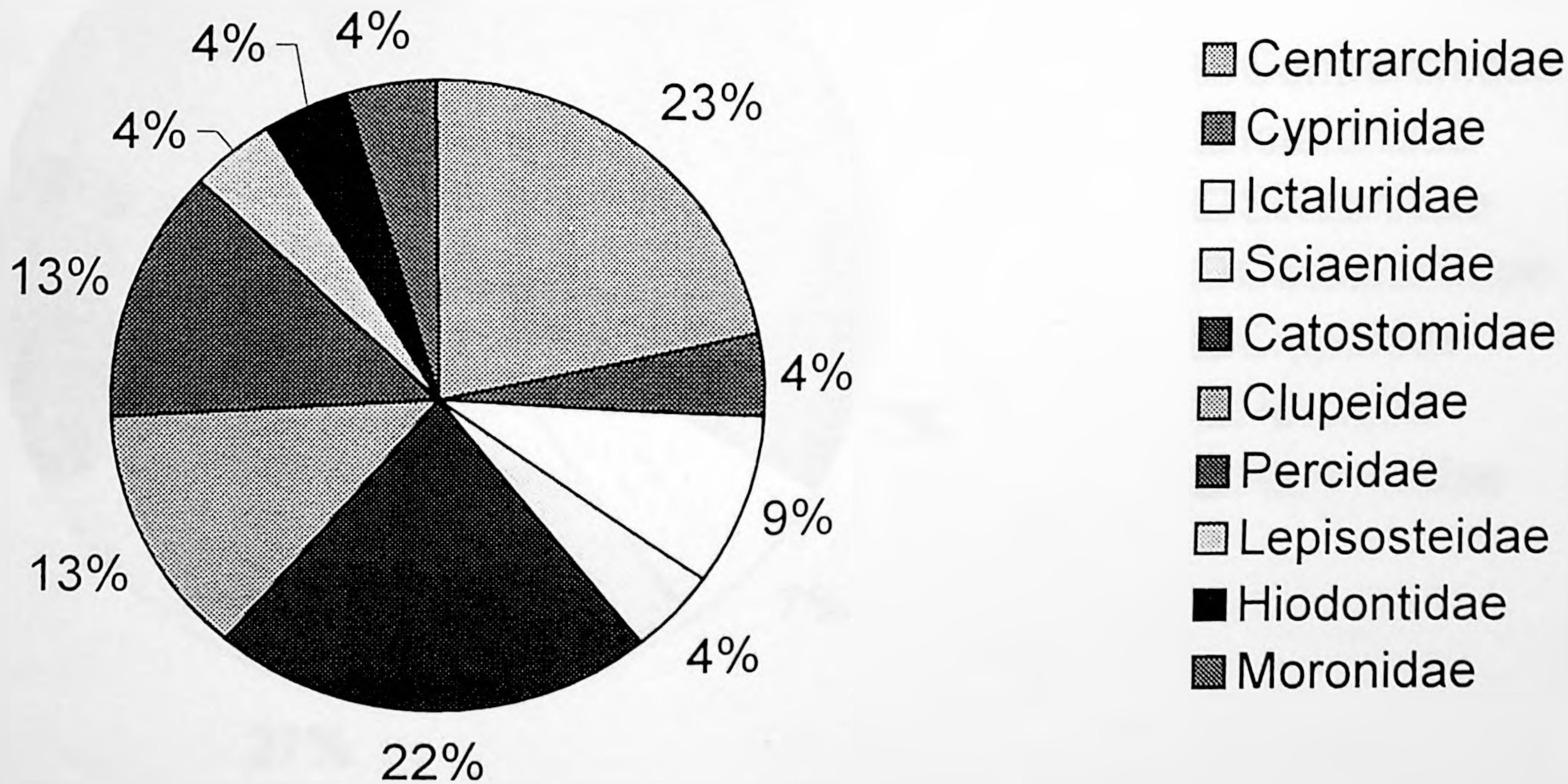

Fig. 128. Percent family composition of species showing positive density correlations along the entire river.

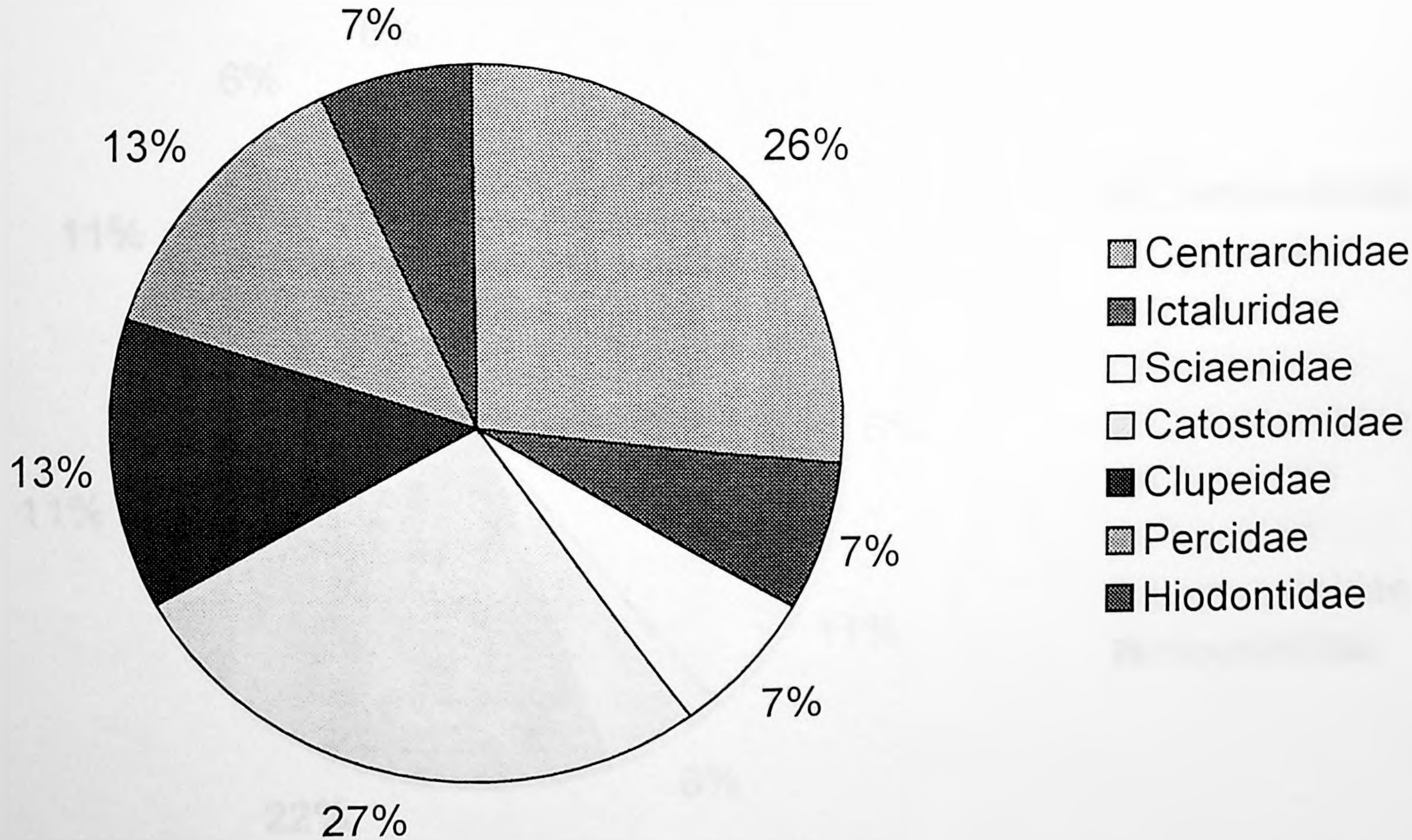

Fig. 129. Percent family composition of species showing positive density correlations along the upper river section.

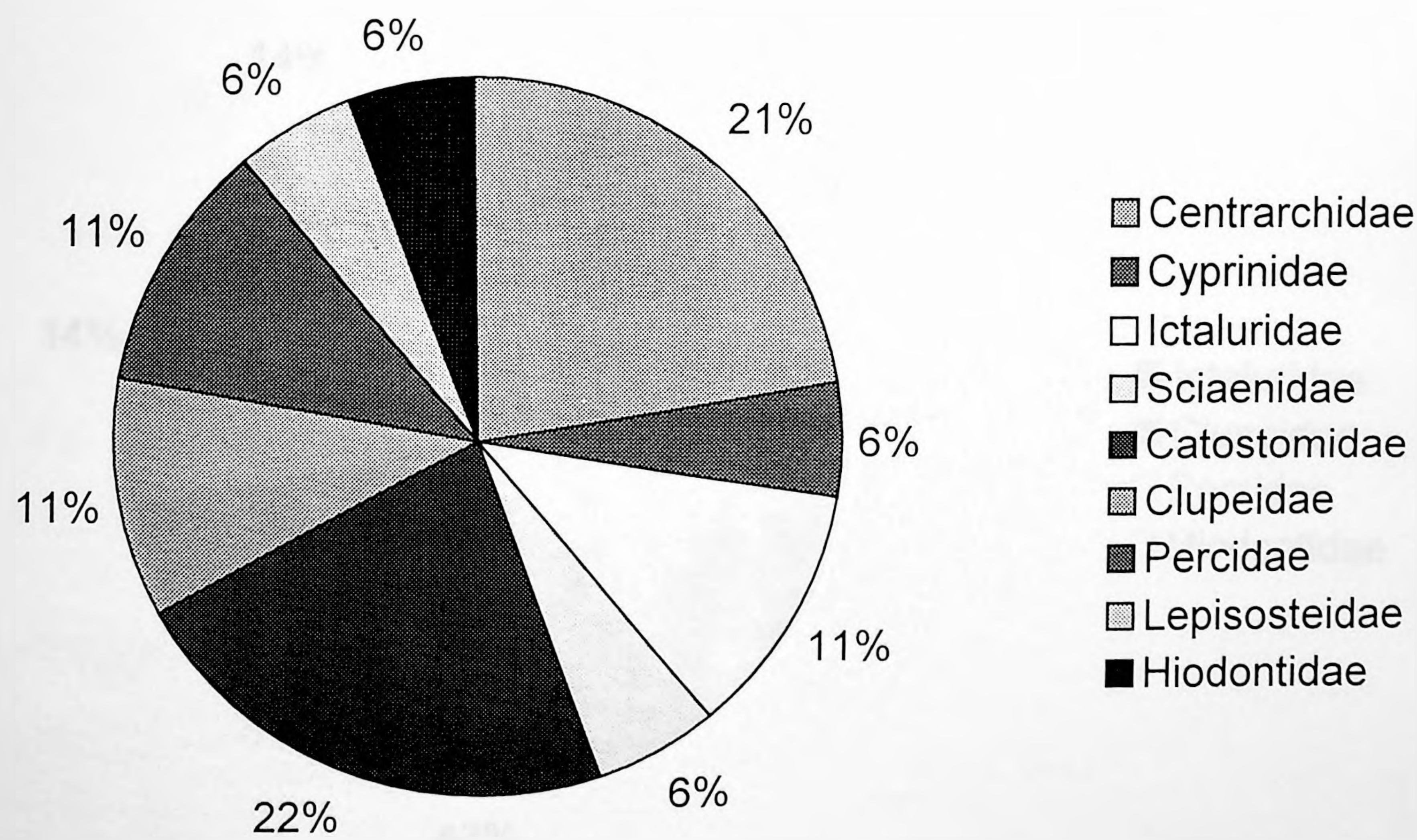

Fig. 130. Percent family composition of species showing positive density correlations along the middle river section.

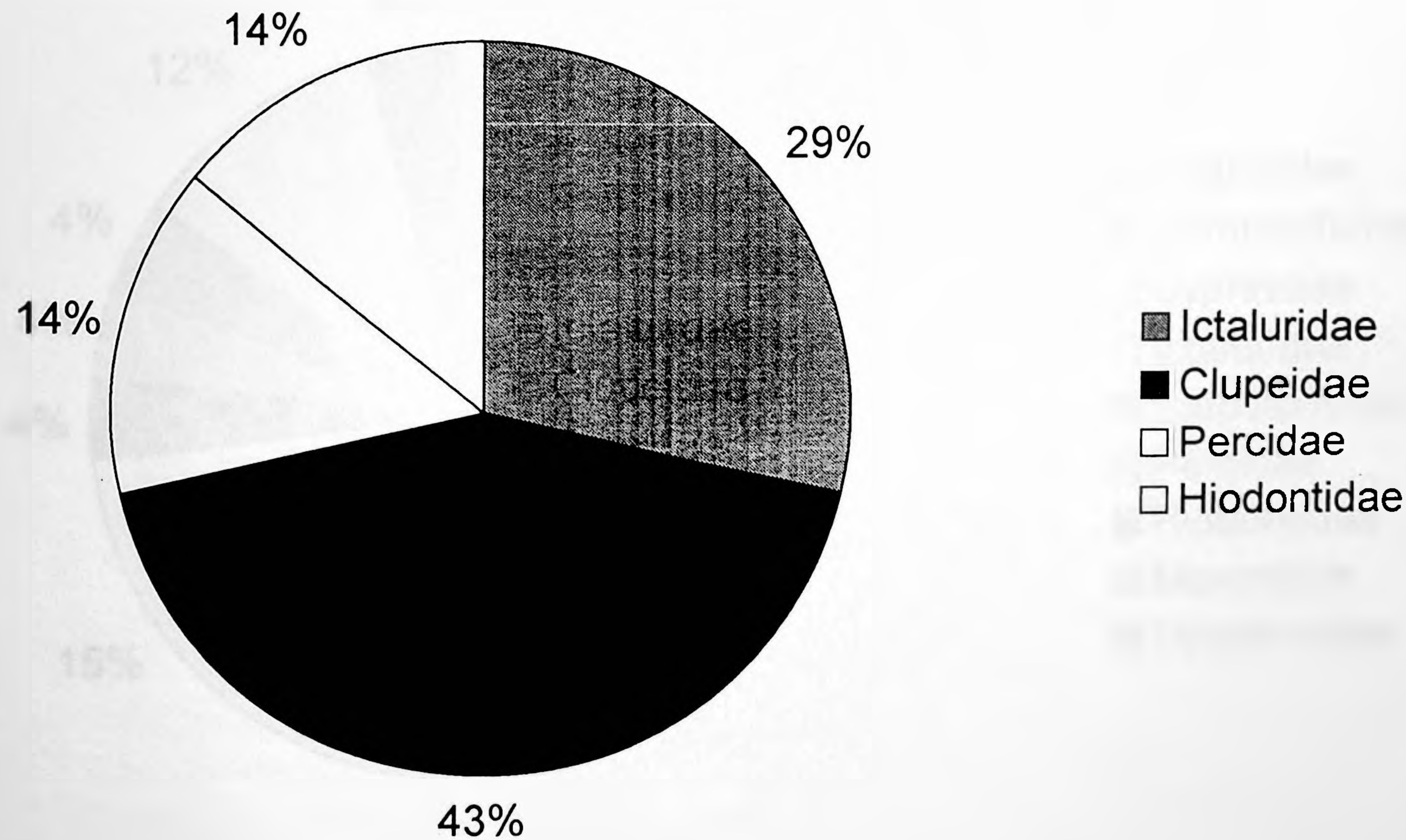

Fig. 131. Percent family composition of species showing positive density correlations along the lower river section.

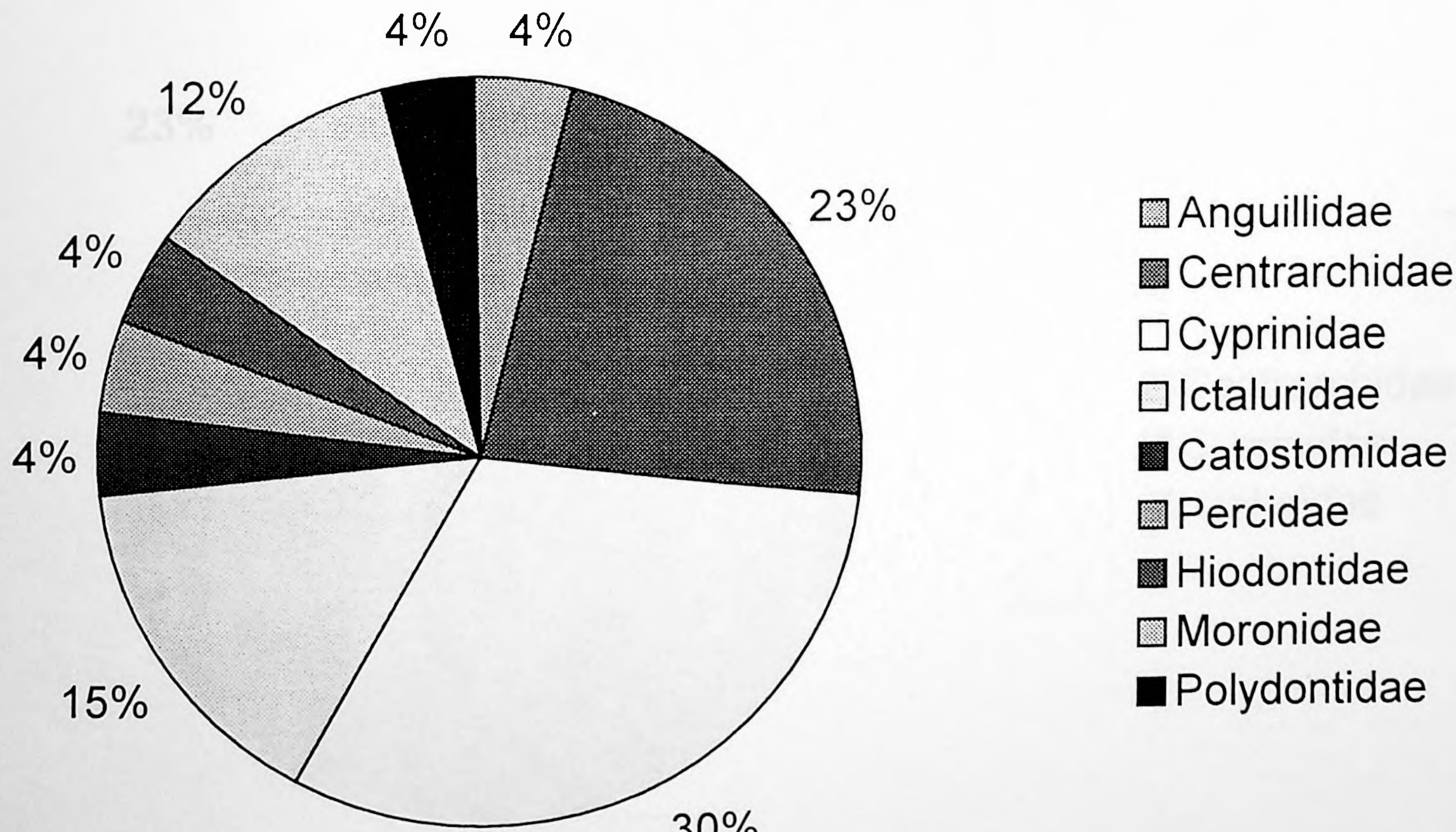

Fig. 132. Percent family composition of species showing density peaks along the entire river.

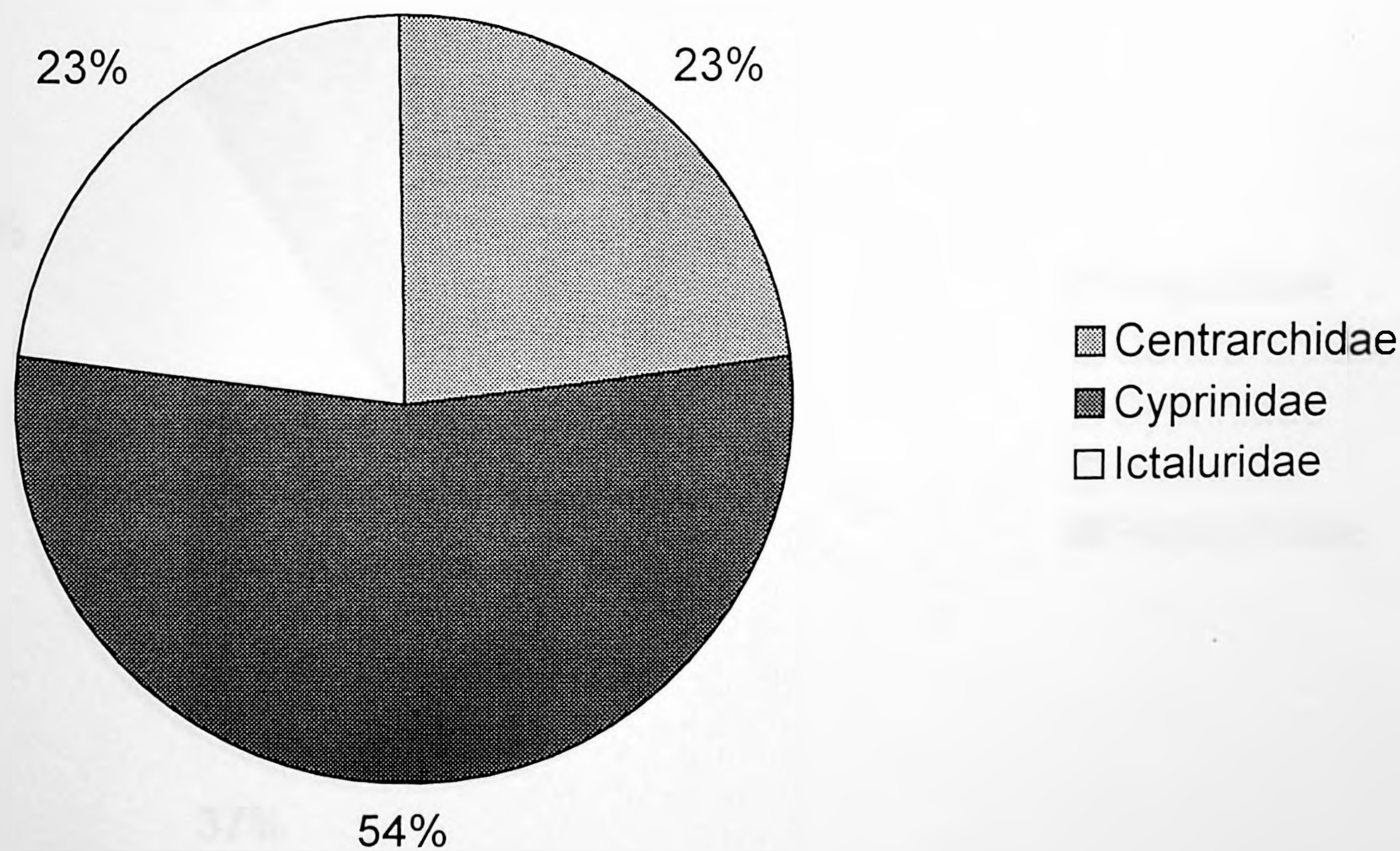

Fig. 133. Percent family composition of species showing density peaks along the upper river section.

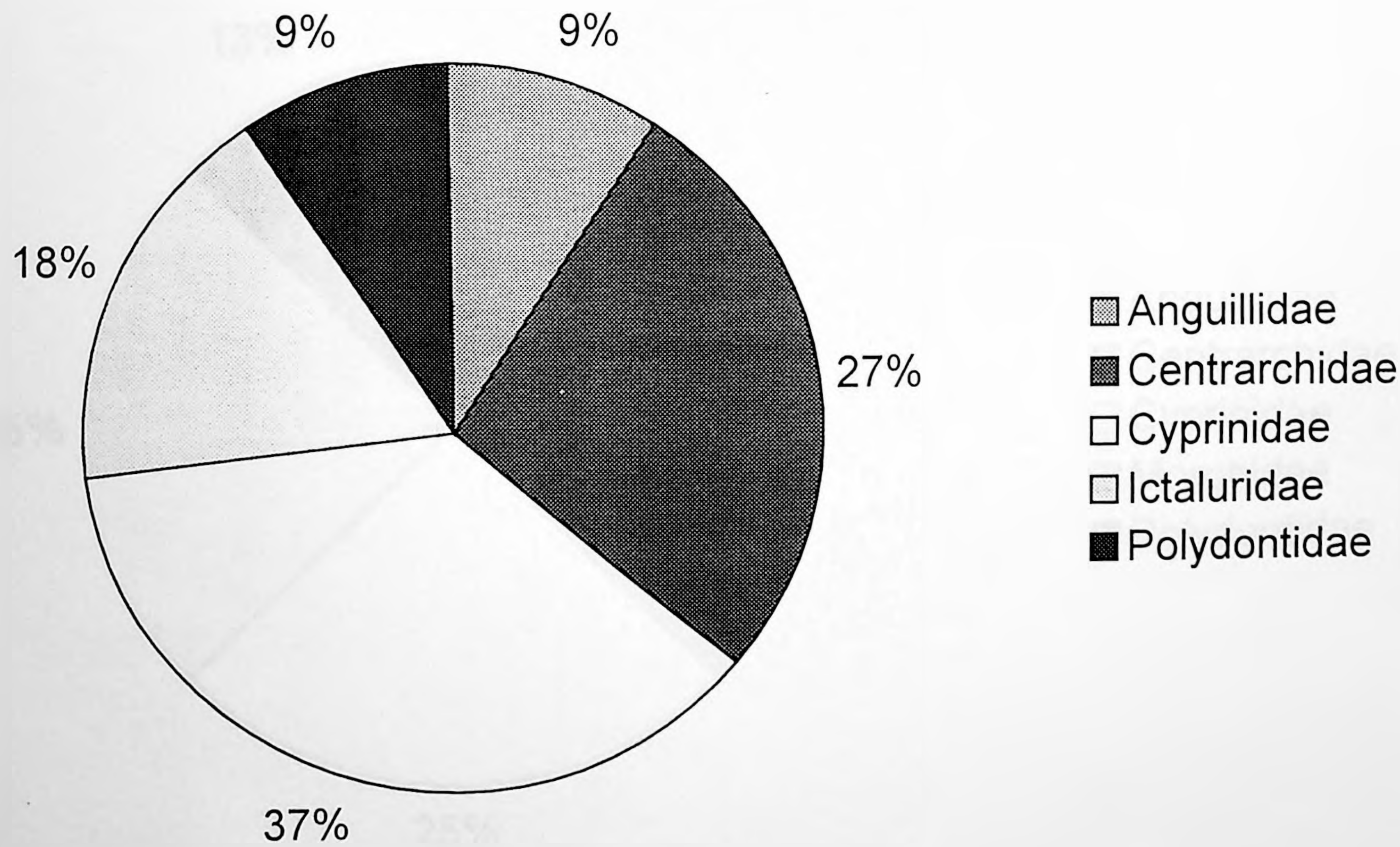

Fig. 134. Percent family composition of species showing density peaks along the middle river section.

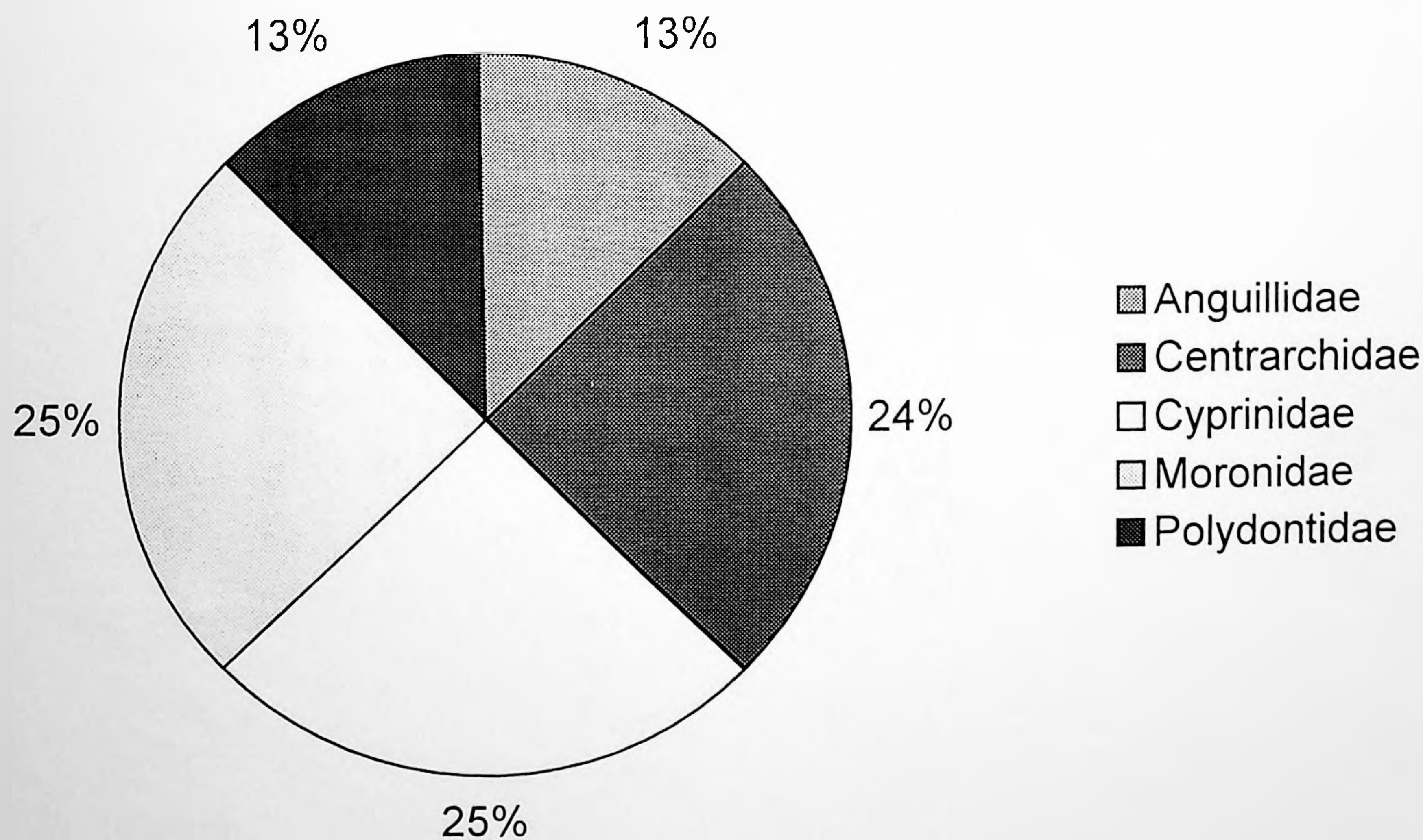

Fig. 135. Percent family composition of species showing density peaks along the lower river section.