# IMPACT OF THERMAL EFFLUENT FROM A STEAM-ELECTRIC STATION ON A MARSHLAND NURSERY AREA DURING THE HOT SEASON

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## ABSTRACT

Seine samples of fishes were collected during the hot season from three similar marshland creeks situated at various distances from a steam-electric station near Jacksonville, Fla. Thermal effluent from the electric station is discharged directly into one creek and enters a second creek on the initial stage of each rising tide. The third creek remained at ambient temperature. Fishes collected in the samples were analyzed for species composition and for density and biomass per unit area. A total of 48 species belonging to 23 families were identified. Thirty-seven species were collected at least once in the ambient temperature creek whereas 30 species were collected in the creek receiving the maximum amount of thermal effluent.

Twenty species appearing in the samples are categorized as utilizable species because they are used by man either as food or for various fishery products. Specimens of all utilizable species were juveniles. In the thermally affected creeks, both the numbers and the biomass per unit area of juveniles of utilizable species were 3- to 10-fold smaller than those obtained in collections from the ambient temperature creek. When data for the entire hot season are considered, the creek receiving the largest input of thermal effluent supported a population of fishes having approximately 19% of its numbers and 32% of its biomass composed of juveniles of utilizable species. In contrast, the ambient temperature creek supported a population having approximately 73% of its numbers and 83% of its biomass composed of such species. Whereas juveniles of two species of mullet (*Mugil curema* and *M. cephalus*) accounted for the majority of the utilizable fishes using the thermally affected creeks as a nursery area, large numbers of juveniles of at least five additional utilizable species occupied the ambient temperature creek. These species were as follows (in order of decreasing abundance): tidewater silverside, *Menidia beryllina*; spot, *Leiostomus xanthurus*; Atlantic menhaden, *Brevoortia tyrannus*; silver perch, *Bairdiella chrysura*; and Atlantic thread herring, *Opisthonema oglinum*.

There is no longer any doubt that estuarine areas play a vital role in the life cycles of the majority of species of finfish and shellfish that are harvested annually in coastal fisheries. The role of estuaries as nursery areas for both sport and commercial species is now well documented (Skud and Wilson 1960; Smith et al. 1966; Sykes and Finucane 1966; Carr and Adams 1973; others). The majority of sport and commercial species must inhabit estuarine areas during at least part of their life cycles. Most frequently it is the early juvenile stages that exhibit the most pronounced estuarine dependence.

Thermal additions from power plants are considered to pose a potentially serious threat to valuable estuarine habitats. Krenkel and Parker (1969) have estimated that the amount of water required for condenser cooling by power plants in this country will increase from 50 trillion gallons per year in 1968 to 100 trillion gallons per year by 1980. This latter amount represents approximately one-fifth of the total land runoff in the contiguous United States. The immense volumes of water required for cooling by power plants are most readily obtained by building these plants adjacent to estuaries or in other coastal locations. The fact that estuarine areas "are among the most productive natural ecosystems in the world" (Schelske and Odum 1962) raises the question as to whether meeting the increasing needs for electricity by our growing population is best satisfied by using estuarine areas as the receiving waters for ever increasing discharges of thermal effluents.

Although a large literature exists concerning various biological facets of "thermal pollution" (reviews are provided by Naylor 1965; Wurtz and Renn 1965; Krenkel and Parker 1969; Jensen et al. 1969; Coutant 1970, 1971; Sylvester 1972; others) we are aware of no published studies that

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attempted to measure in situ the impact of thermal additions upon the capacity of an estuarine habitat to continue functioning as a viable nursery area, particularly for species of sport and commercial significance. Nugent (1970) provided one of the most complete studies on the effects of a thermal effluent on the estuarine macrofauna in the vicinity of a power station south of Miami, Fla. Nugent concluded that there were both beneficial and harmful effects attributable to the thermal additions but that the overall impact was "detrimental to many of the economically valuable animals of the waterway." Nugent found that during the hot summer months the heated effluent decreased the number of fishes present in the discharge area and also contributed to the death of certain organisms. However, the methods used in this study for the collection of fishes (gill nets, traps, and hoop nets) are unsuitable for the collection of many juvenile specimens and are somewhat inappropriate for estimates of density and standing crop. Grimes (1971) and Grimes and Mountain (1971) studied the effects of a thermal effluent upon marine fishes in the vicinity of a power station near Crystal River, Fla. Their major conclusions were that the natural seasonal abundance and the diversity of fishes were slightly altered by fishes being attracted into the heated area during late fall and early winter and by being repulsed during the summer. However the collecting methods and the station locations used in this study make the data difficult to assess in terms of the impact of the thermal effluent on the nursery area capacity of the affected area.

The current study was designed to evaluate in quantitative terms the impact that the discharge of a thermal effluent by a steam electric station had upon the capacity of an estuarine habitat to continue functioning as a nursery area during the hot season. This study was conducted in a marshland area to the northeast of Jacksonville, Fla. The data were obtained by analyzing the contents of seine samples taken from shallow-water stations located in three marshland creeks situated in the vicinity of the power station.

# METHODS

## Description of Study Area

San Carlos Creek, a small marshland creek draining into the St. Johns River, receives the discharge of thermal effluent from the Northside Generating Station (NGS) operated for the city of Jacksonville by the Jacksonville Electric Authority (see Figure 1). The NGS is situated in a relatively undeveloped marshland area to the northeast of Jacksonville approximately 10 miles west of the juncture of the St. Johns River with the Atlantic Ocean. Currently the NGS has two, of an anticipated three, oil-fired steam-electric units on line. Units 1 and 2 of the NGS (550-MW generating capacity) discharge approximately 280,000 gallons/min of thermal effluent directly into San Carlos Creek via outfalls situated 150 ft apart. The completion of Unit 3 (550 MW) in 1976 will result in the discharge of an additional 280,000 gallons/min of thermal effluent into this same creek. Cooling water for the NGS enters via a flume from the St. Johns River and the heated effluent is discharged into San Carlos Creek at a point approximately 0.75 mile upstream from the river.

San Carlos Creek and two other physically similar creeks located adjacent to the site described above were used for the collection of fishes described in the current study. San Carlos Creek not only receives directly the thermal effluent from

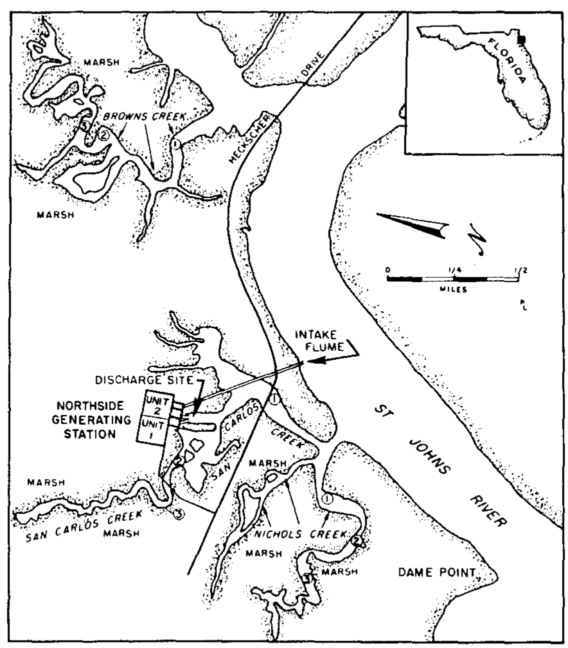


FIGURE 1.—Study area showing location of Northside Generating Station and marshland creeks adjacent to St. Johns River north of Jacksonville, Fla (see inset). Locations of sampling stations in San Carlos Creek, Nichols Creek, and Browns Creek are indicated by numbers. Juncture of river and ocean is situated about 10 miles to the east.

the NGS but on each rising tide this effluent is backed up by tidal action and much of it is retained within the confines of this creek. At this time the thermal effects extend to the uppermost reaches of the creek. A second creek, Nichols Creek (see Figure 1), receives an injection of thermal effluent during the initial stage of each rising tide. Nichols Creek converges with San Carlos Creek just prior to the juncture of both with the river. A major branch of a third creek, Browns Creek, is situated approximately 1 mile east of San Carlos Creek and is completely beyond the zone of thermal influence produced by the power plant. Browns Creek served as a "control" creek that remained at ambient temperature.

The three creeks are physically quite similar in terms of their size, depth, and contiguous marshland and upland areas. The substrate in each consists primarily of soft black mud rich in organic material. Scattered bars of a firmer sand-mud composition are present. Each creek is lined on either side with marsh grasses, primarily *Spartina alterniflora* and *Juncus roemarianus*. No submerged sea grass or other attached macrophytes are present in the creek beds themselves. The major variables affecting differentially the habitats of the three creeks are the thermal effluent, the chemical agents used in the cleaning of condenser tubes, and the clearing and alteration of the landscape necessary for the construction of the power plant.

## Sampling Stations

Three sampling stations were established in each of the three creeks (see Figure 1). One of the stations in each creek was situated near the creek mouth whereas the other two were situated at appropriate distances upstream. The station sites in each creek were selected such that two stations were situated at the sites of juncture of small adjoining creeklets and the third at the edge of a bar. During the hot season of 1973, samples were taken from all nine stations during June and July and from seven of the stations in September.

## Collecting Methods

Fishes were collected at all stations with a bag seine (50 × 6 ft) constructed of 3/8-inch stretch mesh netting. The dimensions of the area seined in each sample were measured with a steel tape at the time the sample was taken. Areas sampled at the stations varied somewhat according to the particular configuration of each seine haul; these areas ranged from 102 to 403 m$^2$ per station. During each sampling period, all seine hauls were made during the day on consecutive days within 1.5 h of low tide. Specimens were preserved immediately in 20% Formalin[3]-seawater and later washed with tap water and stored in 75% isopropyl alcohol. Determinations of biomass are based on weights of preserved specimens. Invertebrates obtained in the samples were also retained for future analysis.

A Beckman electrodeless induction salinometer was used to obtain measurements of temperature and salinity.

Quantitative core samples and plankton samples were also taken but their analyses are incomplete and they are not reported here.

## Presentation of Data

To minimize the number of tables and figures necessary for the presentation of data, analyses of the samples taken from the three stations in each creek have been pooled for each monthly collection. Although this method prohibits comparisons of variations between individual stations within a particular creek, this procedure provides a more direct means of analyzing and comparing the overall population structure within each creek.

# RESULTS

Table 1 presents temperature and salinity measurements taken from San Carlos Creek, Nichols Creek, and Browns Creek during the study period. The temperature data from Browns Creek, which is beyond the range of thermal influence produced by the power station, can be used as a measure of the daytime ambient temperature regime for a creek in this area. During the June sampling period, the average recorded temperature of water discharged by Units 1 and 2 of the NGS into San Carlos Creek was from 5.6° to 7.7°C above the average temperatures recorded at the three stations in Browns Creek. During July, San Carlos Creek received water from the power station that averaged 8.0° to 8.9°C higher than the averages recorded in Browns Creek. During September, this differential increased to 9.1° to 10.8°C. The highest temperature that we recorded

[3]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

TABLE 1.—Daytime measurements of temperature and salinity recorded during the hot season of 1973 from three creeks in the vicinity of the Northside Generating Station, Jacksonville, Fla.

| | San Carlos Creek | | | Nichols Creek | | | Brown Creek | | | Outfalls in San Carlos Creek | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Stn. 1 | Stn. 2 | Stn. 3 | Stn. 1 | Stn. 2 | Stn. 3 | Stn. 1 | Stn. 2 | Stn. 3 | Unit 1 | Unit 2 |
| 23-27 June: | | | | | | | | | | | |
| Temperature, °C: | | | | | | | | | | | |
| Maximum | 35.9 | 35.0 | 36.4 | 31.1 | 32.6 | 34.6 | 30.5 | 30.5 | [1]27.9 | 36.5 | 37.8 |
| Minimum | 30.3 | 31.0 | 30.0 | 27.8 | 28.2 | 27.6 | 26.7 | 26.9 | | 31.8 | 33.9 |
| Average | 33.1 | 33.1 | 33.5 | 29.4 | 29.9 | 30.2 | 28.5 | 28.5 | | 34.1 | 36.2 |
| Salinity, ‰: | | | | | | | | | | | |
| Maximum | 30.6 | 30.1 | 29.0 | 27.0 | 26.6 | 25.6 | 27.5 | 26.2 | [1]21.7 | 31.0 | 31.0 |
| Minimum | 20.7 | 24.7 | 18.2 | 18.9 | 18.3 | 18.7 | 18.3 | 17.7 | | 23.3 | 24.2 |
| Average | 25.9 | 27.3 | 25.6 | 21.9 | 21.9 | 21.7 | 22.6 | 22.3 | | 26.5 | 26.8 |
| 25-26 July: | | | | | | | | | | | |
| Temperature, °C: | | | | | | | | | | | |
| Maximum | 38.0 | 38.2 | 39.2 | 37.5 | 37.3 | 35.8 | 31.2 | 30.6 | 31.6 | 39.7 | 39.4 |
| Minimum | 30.4 | 33.9 | 32.8 | 30.1 | 30.4 | 31.6 | 29.2 | 29.7 | 29.8 | 36.9 | 38.5 |
| Average | 35.3 | 35.7 | 35.5 | 32.3 | 32.4 | 32.9 | 30.2 | 30.2 | 30.5 | 38.5 | 39.1 |
| Salinity, ‰: | | | | | | | | | | | |
| Maximum | 31.2 | 29.8 | 31.0 | 31.5 | 31.3 | 29.3 | 27.5 | 27.3 | 27.2 | 30.8 | 30.8 |
| Minimum | 23.3 | 26.2 | 26.6 | 23.5 | 23.6 | 24.1 | 25.5 | 21.8 | 21.7 | 25.7 | 25.2 |
| Average | 28.1 | 28.9 | 28.8 | 27.4 | 27.6 | 26.0 | 26.5 | 25.2 | 25.1 | 29.2 | 29.2 |
| 19-20 September: | | | | | | | | | | | |
| Temperature, °C: | | | | | | | | | | | |
| Maximum | 37.3 | 37.7 | 37.9 | 36.2 | —[2] | 35.0 | 29.7 | 29.6 | 27.5 | 37.6 | 38.4 |
| Minimum | 30.6 | 32.3 | 32.1 | 28.5 | | 27.9 | 27.3 | 26.5 | 27.0 | 37.4 | 37.8 |
| Average | 34.3 | 36.2 | 36.3 | 31.5 | | 31.4 | 28.4 | 27.9 | 27.3 | 37.5 | 38.1 |
| Salinity, ‰: | | | | | | | | | | | |
| Maximum | 26.4 | 24.3 | 24.3 | 24.8 | —[2] | 24.7 | 27.2 | 26.2 | 26.4 | 23.2 | 24.0 |
| Minimum | 19.5 | 22.1 | 22.7 | 18.1 | | 21.6 | 21.9 | 20.8 | 19.6 | 20.6 | 21.0 |
| Average | 22.0 | 23.2 | 23.5 | 22.4 | | 23.4 | 24.6 | 22.7 | 23.0 | 22.0 | 22.5 |

[1]Only one recording.
[2]Not recorded.

was 39.7°C taken at the outfall of Unit 2. The data shown in Table 1 suggest that the thermal regime present in Nichols Creek was somewhat intermediate between that of the other two creeks. However this is not entirely the case. During the initial phase of each rising tide, tidal action causes the injection of heated effluent from the power plant up the entire length of Nichols Creek. On 19 September, we recorded this injection as it reached and later passed Station 1 in this creek (see Figure 2). The highest temperature recorded at Station 1 during this day was 36.2°C. The passage time of this injection of hot water was approximately 2 h with temperatures greater than 34°C lasting approximately 1 h. Only a slight drop in temperature was apparent when the hot water reached Station 3 situated approximately 0.6 mile away (see Figure 2). Hence, whereas the minimum and average temperatures in Nichols Creek are more similar to those of Browns Creek than to those in San Carlos Creek, the maximum temperatures in Nichols Creek are more similar to those in San Carlos Creek. Consequently, at the onset of each rising tide (twice daily), organisms living in Nichols Creek are subjected to a period of 1- or 2-h duration during which the water temperature is markedly above ambient and almost as high as that in San Carlos Creek.

Table 2 provides a list of the species of fishes collected from the three creeks during the hot season of 1973. A total of 48 species belonging to 23 families were collected. Aside from the Cyprinodontidae and certain of the Gerreidae and

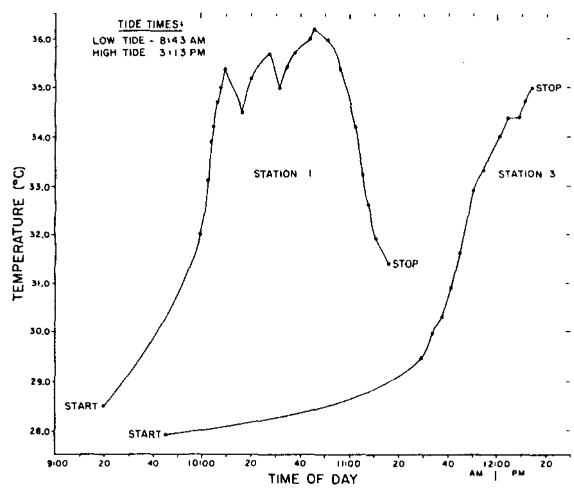


FIGURE 2.—Recordings of water temperature taken in Nichols Creek on the initial stage of rising tide, 19 September 1973. Appearance of thermal effluent from the power plant is indicated by the sudden increases in temperature at Stations 1 and 3.

TABLE 2.—List of fishes collected during the hot season of 1973 from three creeks in the vicinity of the Northside Generating Station, Jacksonville, Fla.

| Family | Scientific name | Common name[1] | Class[2] | Species utilized[3] |
|---|---|---|---|---|
| Elopidae | *Elops saurus* | Ladyfish | J | X |
| Clupeidae | *Brevoortia tyrannus*[4] | Atlantic menhaden | J | X |
| | *Opisthonema oglinum* | Atlantic thread herring | J | X |
| Engraulidae | *Anchoa hepsetus* | Striped anchovy | J | |
| | *Anchoa mitchilli* | Bay anchovy | J | |
| Synodontidae | *Synodus foetens* | Inshore lizardfish | J | |
| Ariidae | *Arius felis* | Sea catfish | J | |
| Batrachoididae | *Opsanus tau* | Oyster toadfish | J | |
| Belonidae | *Strongylura marina* | Atlantic needlefish | J | |
| Cyprinodontidae | *Cyprinodon variegatus* | Sheepshead minnow | J-A | |
| | *Fundulus grandis* | Gulf killifish | J-A | |
| | *Fundulus heteroclitus* | Mummichog | J-A | |
| | *Fundulus majalis*[5] | Striped killifish | J-A | |
| Poeciliidae | *Gambusia affinis* | Mosquitofish | J-A | |
| | *Poecilia latipinna* | Sailfin molly | J-A | |
| Atherinidae | *Menidia beryllina* | Tidewater silverside | J | X |
| Syngnathidae | *Syngnathus floridae* | Dusky pipefish | J | |
| Carangidae | *Caranx hippos* | Crevalle jack | J | X |
| | *Chloroscombrus chrysurus* | Atlantic bumper | J | |
| | *Selene vomer* | Lookdown | J | |
| | *Trachinotus falcatus* | Permit | J | X |
| Lutjanidae | *Lutjanus griseus* | Gray snapper | J | X |
| Gerreidae | *Diapterus olisthostomus* | Irish pompano | J | |
| | *Eucinostomous argenteus* | Spotfin mojarra | J-A | |
| | *Eucinostomous gula* | Silver jenny | J | |
| | *Gerres cinereus* | Yellowfin mojarra | J | X |
| Sparidae | *Archosargus probatocephalus* | Sheepshead | J | X |
| | *Lagodon rhomboides* | Pinfish | J | X |
| Sciaenidae | *Bairdiella chrysura* | Silver perch | J | X |
| | *Cynoscion nebulosus* | Spotted seatrout | J | X |
| | *Leiostomus xanthurus* | Spot | J | X |
| | *Micropogon undulatus* | Atlantic croaker | J | X |
| | *Pogonias cromis* | Black drum | J | X |
| | *Sciaenops ocellata* | Red drum | J | X |
| Ephippidae | *Chaetodipterus faber* | Atlantic spadefish | J | X |
| Mugilidae | *Mugil cephalus* | Striped mullet | J | X |
| | *Mugil curema* | White mullet | J | X |
| Gobiidae | *Gobionellus boleosoma* | Darter goby | J | |
| | *Gobionellus hastatus* | Sharptail goby | J-A | |
| | *Gobionellus smaragdus* | Emerald goby | J | |
| | *Gobiosoma bosci* | Naked goby | J | |
| | *Microgobius gulosus* | Clown goby | J-A | |
| Triglidae | *Prionotus tribulus* | Bighead searobin | J | |
| Bothidae | *Citharichthys spilopterus* | Bay whiff | J | |
| | *Etropus crossotus* | Fringed flounder | J | |
| | *Paralichthys lethostigma* | Southern flounder | J | X |
| Cynoglossidae | *Symphurus plagiusa* | Blackcheek tonguefish | J | |
| Tetraodontidae | *Sphoeroides nephelus* | Southern puffer | J | |

[1]Common names recommended by Bailey (1970) are used.
[2]J = juvenile; A = adult.
[3]Species utilized refers to either sport species or to species cited by Lyles (1969:463-487) as being used by man for food or related fishery products.
[4]Some of these specimens may have been *B. smithii* and/or hybrids of *Brevoortia smithii* as described by Dahlberg (1970). Since they were all juvenile specimens the major characters given by Dahlberg for distinguishing between the three possibilities were extremely difficult to apply with certainty.
[5]According to Carter R. Gilbert (pers. commun.) of the Florida State Museum, some of these specimens may have been *F. similis*. The taxonomic status of the two species on the northeast coast of Florida is somewhat uncertain.

Gobiidae, all of the specimens were juveniles that were using the creeks as a nursery area. Twenty of the species are utilized directly by man, i.e., are species used for food and/or related fishery products including sport species and bait fishes. Subsequent references to "utilizable species" refer to those used by man as defined above.

Tables 3-5 provide monthly summaries of the numbers of individuals and the estimated densities of all fish species collected from the three creeks. Of the 48 species obtained in one or more collections, 30 were collected at least once in San Carlos Creek, 23 were collected in Nichols Creek, and 37 appeared in Browns Creek. Four species, *Cyprinodon variegatus* and three species of gobies (*Gobionellus smaragdus*, *Gobiosomo bosci*, and *Microgobius gulosus*), were collected only in San Carlos Creek thereby suggesting that they preferred the high temperature regime afforded there. However, the three species of gobies appeared only in the June samples. Eleven other species of temperature tolerant fishes were present in San Carlos Creek at densities that were either as great, or greater, than the densities present in the ambient temperature creek. These species were as follows (in order of decreasing

TABLE 3.—Collections of fishes from three stations on San Carlos Creek during the hot season of 1973. Area seined in June was 706 $m^2$, in July was 563 $m^2$, and in September was $563^2$. Total area seined was 1,832 $m^2$.

| Family | Species | June collection | | July collection | | September collection | | Total collections | |
|---|---|---|---|---|---|---|---|---|---|
| | | No. | No./100 $m^2$ | No. | No./100 $m^2$ | No. | No./100 $m^2$ | No. | No./100 $m^2$ |
| Elopidae | *Elops saurus* | 3 | 0.4 | — | — | 1 | 0.2 | 4 | 0.2 |
| Clupeidae | *Brevoortia tyrannus* | — | — | 4 | 0.7 | — | — | 4 | 0.2 |
| | *Opisthonema oglinum* | — | — | 6 | 1.1 | — | — | 6 | 0.3 |
| Engraulidae | *Anchoa hepsetus* | 1 | 0.1 | — | — | — | — | 1 | 0.05 |
| Belonidae | *Strongylura marina* | 1 | 0.1 | — | — | — | — | 1 | 0.05 |
| Cyprinodontidae | *Cyprinodon variegatus* | 10 | 1.4 | 4 | 0.7 | 12 | 2.1 | 26 | 1.4 |
| | *Fundulus grandis* | 62 | 8.8 | 161 | 28.6 | 179 | 31.6 | 402 | 21.9 |
| | *Fundulus heteroclitus* | 192 | 27.2 | 669 | 118.8 | 405 | 72.1 | 1266 | 69.2 |
| | *Fundulus majalis* | 15 | 2.1 | 44 | 7.8 | 50 | 8.9 | 109 | 5.9 |
| Poeciliidae | *Gambusia affinis* | — | — | 5 | 0.9 | 2 | 0.4 | 7 | 0.4 |
| | *Poecilia latipinna* | 40 | 5.7 | 44 | 7.8 | 31 | 5.5 | 115 | 6.3 |
| Atherinidae | *Menidia beryllina* | 2 | 0.3 | — | — | 5 | 0.7 | 7 | 0.4 |
| Lutjanidae | *Lutjanus griseus* | — | — | — | — | 4 | 0.7 | 4 | 0.2 |
| Gerreidae | *Diapterus olisthostomus* | — | — | — | — | 1 | 0.2 | 1 | 0.05 |
| | *Eucinostomous argenteus* | 137 | 19.4 | 36 | 6.4 | 693 | 123.1 | 866 | 47.3 |
| | *Eucinostomous gula* | — | — | — | — | 3 | 0.5 | 3 | 0.2 |
| | *Gerres cinereus* | 1 | 0.1 | 2 | 0.4 | 3 | 0.5 | 6 | 0.3 |
| Sparidae | *Lagodon rhomboides* | 1 | 0.1 | — | — | — | — | 1 | 0.05 |
| Sciaenidae | *Cynoscion nebulosus* | 1 | 0.1 | — | — | 2 | 0.4 | 3 | 0.2 |
| | *Leiostomus xanthurus* | 44 | 6.2 | — | — | — | — | 44 | 2.4 |
| | *Pogonias cromis* | 4 | 0.6 | — | — | — | — | 4 | 0.2 |
| | *Sciaenops ocellata* | 1 | 0.1 | — | — | — | — | 1 | 0.05 |
| Mugilidae | *Mugil cephalus* | 40 | 5.7 | 13 | 2.3 | 1 | 0.2 | 54 | 2.9 |
| | *Mugil curema* | 211 | 29.9 | 292 | 51.9 | 42 | 7.5 | 545 | 29.7 |
| Gobiidae | *Gobionellus boleosoma* | 5 | 0.7 | — | — | — | — | 5 | 0.3 |
| | *Gobionellus hastatus* | 12 | 1.7 | 2 | 0.4 | — | — | 14 | 0.8 |
| | *Gobionellus smaragdus* | 2 | 0.3 | — | — | — | — | 2 | 0.1 |
| | *Gobiosoma bosci* | 1 | 0.1 | — | — | — | — | 1 | 0.05 |
| | *Microgobius gulosus* | 3 | 0.4 | — | — | — | — | 3 | 0.2 |
| Bothidae | *Citharichthys spilopterus* | 3 | 0.4 | — | — | — | — | 3 | 0.2 |
| | Total | 792 | 111.9 | 1,282 | 227.8 | 1,434 | 254.6 | 3,508 | 191.5 |
| | Total utilizable species | 308 | 43.5 | 317 | 56.4 | 58 | 10.2 | 683 | 37.1 |

abundance): *Fundulus heteroclitus*, *Eucinostomous argenteus*, *Mugil curema*, *F. grandis*, *Poecilia latipinna*, *F. majalis*, *Gobionellus hastatus*, *Gambusia affinis*, *Gerres cinereus*, *Elops saurus*, and *Lutjanus griseus*.

Eleven species, *Synodus foetens*, *Opsanus tau*, *Syngnathus floridae*, *Chloroscombrus chrysurus*, *Selene vomer*, *Micropogon undulatus*, *Chaetodipterus faber*, *Prionotus tribulus*, *Etropus crossotus*, *Paralichthys lethostigma*, and

TABLE 4.—Collections of fishes from three stations on Nichols Creek during the hot season of 1973. Area seined in June was 819 $m^2$, in July was 815 $m^2$, and in September 714 $m^2$. Total area seined was 2,348 $m^2$.

| Family | Species | June collection | | July collection | | September collection[1] | | Total collections | |
|---|---|---|---|---|---|---|---|---|---|
| | | No. | No./100 $m^2$ | No. | No./100 $m^2$ | No. | No./100 $m^2$ | No. | No./100 $m^2$ |
| Clupeidae | *Brevoortia tyrannus* | 1 | 0.1 | — | — | — | — | 1 | 0.04 |
| Engraulidae | *Anchoa mitchilli* | 36 | 4.4 | — | — | — | — | 36 | 1.5 |
| Ariidae | *Arius felis* | — | — | 1 | 0.1 | — | — | 1 | 0.04 |
| Cyprinodontidae | *Fundulus grandis* | 77 | 9.4 | 55 | 6.7 | — | — | 132 | 5.6 |
| | *Fundulus heteroclitus* | 346 | 42.2 | 766 | 94.0 | 10 | 1.4 | 1122 | 47.8 |
| | *Fundulus majalis* | 4 | 0.5 | 4 | 0.5 | — | — | 8 | 0.3 |
| Poeciliidae | *Poecilia latipinna* | — | — | 12 | 1.5 | — | — | 12 | 0.5 |
| Atherinidae | *Menidia beryllina* | 13 | 1.6 | 11 | 1.3 | 102 | 14.3 | 126 | 5.4 |
| Carangidae | *Caranx hippos* | — | — | — | — | 2 | 0.3 | 2 | 0.1 |
| | *Trachinotus falcatus* | — | — | 1 | 0.1 | — | — | 1 | 0.04 |
| Gerreidae | *Diapterus olisthostomus* | 1 | 0.1 | — | — | — | — | 1 | 0.04 |
| | *Eucinostomous argenteus* | 168 | 20.5 | 246 | 30.2 | 103 | 14.4 | 517 | 22.0 |
| | *Eucinostomous gula* | — | — | 49 | 6.0 | 12 | 1.7 | 61 | 2.6 |
| Sparidae | *Archosargus probatocephalus* | — | — | 1 | 0.1 | — | — | 1 | 0.04 |
| | *Lagodon rhomboides* | — | — | 1 | 0.1 | — | — | 1 | 0.04 |
| Sciaenidae | *Bairdiella chrysura* | — | — | — | — | 1 | 0.1 | 1 | 0.04 |
| | *Leiostomus xanthurus* | 105 | 12.8 | 47 | 5.8 | 6 | 0.8 | 158 | 6.7 |
| | *Pogonias cromis* | — | — | 1 | 0.1 | — | — | 1 | 0.04 |
| Mugilidae | *Mugil cephalus* | 121 | 14.8 | 7 | 0.9 | 1 | 0.1 | 129 | 5.5 |
| | *Mugil curema* | 653 | 79.7 | 183 | 22.5 | 35 | 4.9 | 871 | 37.1 |
| Gobiidae | *Gobionellus boleosoma* | 1 | 0.1 | — | — | — | — | 1 | 0.04 |
| | *Gobionellus hastatus* | 1 | 0.1 | — | — | — | — | 1 | 0.04 |
| Bothidae | *Citharichthys spilopterus* | 8 | 1.0 | — | — | 1 | 0.1 | 9 | 0.4 |
| Cynoglossidae | *Symphurus plagiusa* | 2 | 0.2 | — | — | — | — | 2 | 0.1 |
| | Total | 1,537 | 187.5 | 1,385 | 169.9 | 273 | 38.1 | 3,195 | 136.0 |
| | Total utilizable species | 893 | 109.0 | 252 | 30.9 | 147 | 20.5 | 1,292 | 55.0 |

[1]Station 2 not sampled in September due to mechanical problems.

TABLE 5.—Collections of fishes from three stations on Browns Creek during the hot season of 1973. Area seined in June was 685 $m^2$, in July was 676 $m^2$, and in September was 285 $m^2$. Total area seined was 1,646 $m^2$.

| Family | Species | June collection | | July collection | | September collection[1] | | Total collections | |
|---|---|---|---|---|---|---|---|---|---|
| | | No. | No./100 $m^2$ | No. | No./100 $m^2$ | No. | No./100 $m^2$ | No. | No./100 $m^2$ |
| Elopidae | *Elops saurus* | — | — | 1 | 0.1 | — | — | 1 | 0.06 |
| Clupeidae | *Brevoortia tyrannus* | 551 | 80.4 | 420 | 62.1 | — | — | 971 | 59.0 |
| | *Opisthonema oglinum* | — | — | 103 | 15.2 | — | — | 103 | 6.3 |
| Engraulidae | *Anchoa hepsetus* | 21 | 3.1 | — | — | 1 | 0.4 | 22 | 1.3 |
| | *Anchoa mitchilli* | 265 | 38.7 | 377 | 55.8 | 16 | 5.6 | 658 | 40.0 |
| Synodontidae | *Synodus foetens* | 3 | 0.4 | — | — | 1 | 0.4 | 4 | 0.2 |
| Batrachoididae | *Opsanus tau* | 1 | 0.1 | — | — | 1 | 0.4 | 2 | 0.1 |
| Belonidae | *Strongylura marina* | 1 | 0.1 | — | — | — | — | 1 | 0.06 |
| Cyprinodontidae | *Fundulus grandis* | 2 | 0.3 | 3 | 0.4 | 1 | 0.4 | 6 | 0.4 |
| | *Fundulus heteroclitus* | 717 | 105.0 | 342 | 50.6 | 9 | 3.5 | 1,068 | 64.9 |
| | *Fundulus majalis* | 1 | 0.1 | — | — | — | — | 1 | 0.06 |
| Poeciliidae | *Gambusia affinis* | 2 | 0.3 | 4 | 0.6 | 6 | 2.1 | 12 | 0.7 |
| Atherinidae | *Menidia beryllina* | 222 | 32.4 | 2,288 | 338.5 | 80 | 28.1 | 2,590 | 157.4 |
| Syngnathidae | *Syngnathus floridae* | 1 | 0.1 | — | — | 1 | 0.4 | 2 | 0.1 |
| Carangidae | *Caranx hippos* | 1 | 0.1 | 1 | 0.1 | 1 | 0.4 | 3 | 0.2 |
| | *Chloroscombrus chrysurus* | — | — | — | — | 2 | 0.7 | 2 | 0.1 |
| | *Selene vomer* | 2 | 0.3 | 1 | 0.1 | — | — | 3 | 0.2 |
| Lutjanidae | *Lutjanus griseus* | — | — | 1 | 0.1 | 4 | 1.4 | 5 | 0.3 |
| Gerreidae | *Eucinostomous argenteus* | 14 | 2.0 | 79 | 11.7 | 44 | 15.4 | 137 | 8.3 |
| | *Eucinostomous gula* | 2 | 0.3 | 44 | 6.5 | 2 | 0.7 | 48 | 2.9 |
| | *Gerres cinereus* | — | — | 1 | 0.1 | — | — | 1 | 0.06 |
| Sparidae | *Lagodon rhomboides* | 10 | 1.5 | 1 | 0.1 | — | — | 11 | 0.7 |
| Sciaenidae | *Bairdiella chrysura* | 77 | 11.2 | 38 | 5.6 | 4 | 1.4 | 119 | 7.2 |
| | *Cynoscion nebulosus* | — | — | — | — | 1 | 0.4 | 1 | 0.06 |
| | *Leiostomus xanthurus* | 912 | 133.0 | 134 | 19.8 | 25 | 8.8 | 1,071 | 65.1 |
| | *Micropogon undulatus* | 9 | 1.3 | 2 | 0.3 | — | — | 11 | 0.7 |
| | *Sciaenops ocellata* | 4 | 0.6 | — | — | — | — | 4 | 0.2 |
| Ephippidae | *Chaetodipterus faber* | — | — | 2 | 0.3 | — | — | 2 | 0.1 |
| Mugilidae | *Mugil cephalus* | 61 | 8.9 | 31 | 4.6 | 1 | 0.4 | 93 | 5.7 |
| | *Mugil curema* | 238 | 34.7 | 206 | 30.5 | 21 | 7.4 | 465 | 28.3 |
| Gobiidae | *Gobionellus boleosoma* | 1 | 0.1 | 1 | 0.1 | — | — | 2 | 0.1 |
| Triglidae | *Prionotus tribulus* | — | — | 1 | 0.1 | — | — | 1 | 0.06 |
| Bothidae | *Citharichthys spilopterus* | 5 | 0.7 | 4 | 0.6 | — | — | 9 | 0.6 |
| | *Etropus crossotus* | — | — | — | — | 1 | 0.4 | 1 | 0.06 |
| | *Paralichthys lethostigma* | 1 | 0.1 | — | — | — | — | 1 | 0.06 |
| Cynoglossidae | *Symphurus plagiusa* | 1 | 0.1 | 13 | 1.9 | — | — | 14 | 0.9 |
| Tetraodontidae | *Sphoeroides nephelus* | 2 | 0.3 | — | — | 2 | 0.7 | 4 | 0.2 |
| | Total | 3,127 | 456.2 | 4,098 | 605.8 | 224 | 79.4 | 7,449 | 452.7 |
| | Total utilizable species | 2,086 | 304.2 | 3,229 | 477.0 | 137 | 48.3 | 5,452 | 331.4 |

[1]Station 1 not sampled in September due to mechanical problems.

*Sphoeroides nephelus*, were collected only in Browns Creek and not in either of the thermally affected creeks. However, none of the species listed above made a major contribution to the total density of fishes in this ambient temperature creek. Among the other species entirely absent from San Carlos collections, only two species, *Anchoa mitchilli* and *Bairdiella chrysura*, made a significant contribution to the fish density in Browns Creek. When considered alone, the differences cited above might be construed to suggest that the nursery capacity of thermally affected San Carlos Creek is not markedly different from that of Browns Creek which functions at ambient temperature. However, a critical comparison of the densities, the biomasses, and the population structure of the fishes in the three creeks reveal some important differences that are described below.

Figure 3 illustrates the relative densities of both total fishes and utilizable fishes as they appeared in the monthly samples. The figure shows that the following three major differences existed between the populations present in the thermally affected creeks (San Carlos and Nichols) and the population present in the ambient temperature creek (Browns):

1. In June and July the density of total fishes was highest in the ambient temperature creek.
2. Throughout the entire study period the density of utilizable species was markedly higher in the ambient temperature creek.
3. In the ambient temperature creek, the majority of the population consisted of juveniles of utilizable species, whereas in the thermally affected creeks the majority consisted of species not utilized by man.

In June and July the estimated density of total

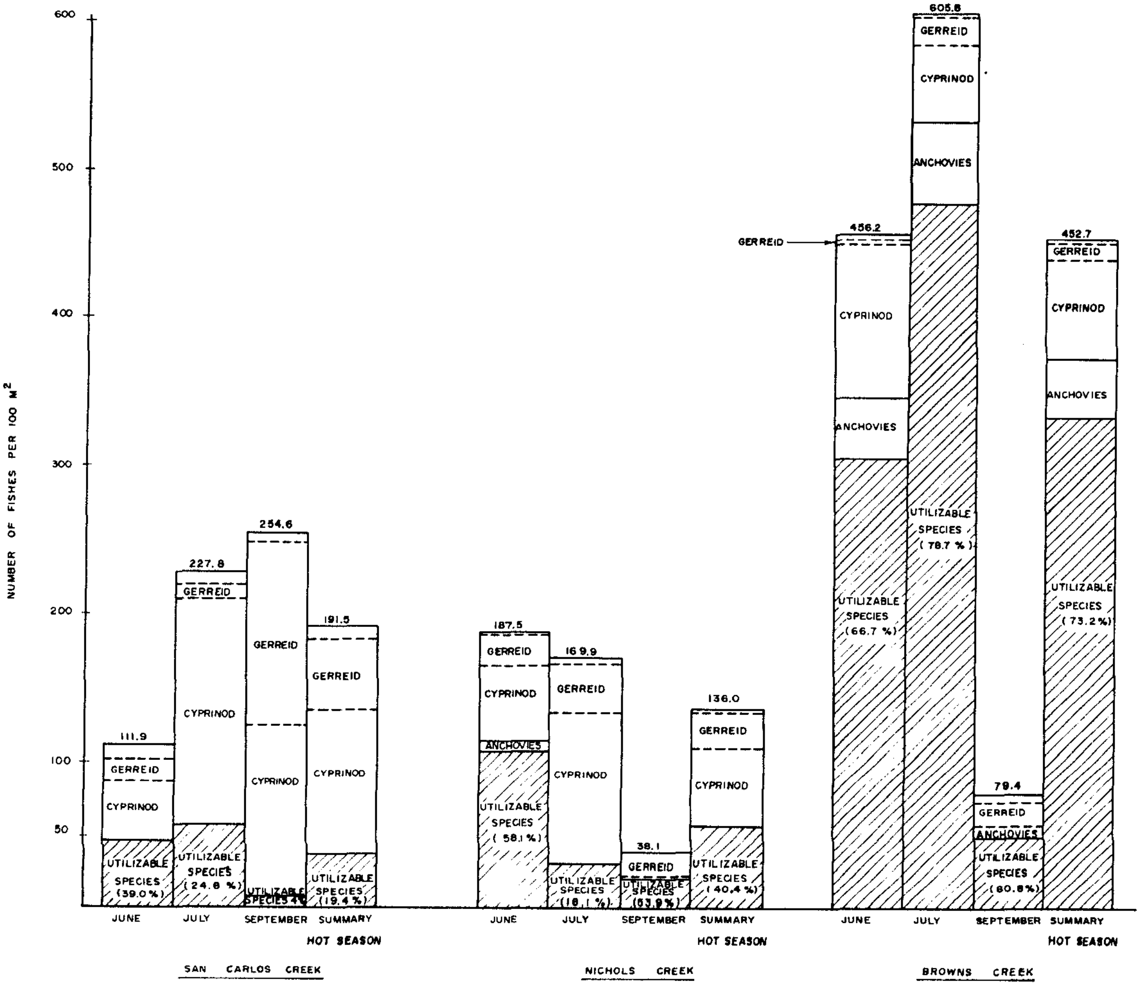


FIGURE 3.—Densities of fishes in the three creeks as estimated from seine collections. Species used by man as food or fishery products are combined and termed Utilizable Species. Percent of each collection that was represented by utilizable species is indicated. Cyprinod = all species of Cyprinodontidae. Gerreid = all species of Gerreidae except for *Gerres cinereus*. The histogram for each creek depicting "Summary Hot Season" was compiled on the basis of the total area sampled during the entire study period.

fishes in Browns Creek was three to four times higher than the estimated density in San Carlos Creek. However, in September the estimated density in San Carlos Creek was about three times higher than that in Browns Creek. The basis for this apparent September reversal between the two creeks was due primarily to the expected early fall emigration of juveniles of migratory species, many of which are utilizable species. The estimated density of total fishes in Browns Creek was two to four times higher than the density in Nichols Creek throughout the entire study period.

Of greater significance than the differences in total density of fishes described above, are the marked differences that existed between creeks in the estimated densities of utilizable species (see Figure 3). In June and July, the estimated density of utilizable species in Browns Creek was seven to eight times greater than in San Carlos Creek. In September following the emigration of juveniles of many migratory species, the estimated density of utilizable species in Browns Creek was still nearly five times greater than that recorded in San Carlos Creek. When data for the entire hot season are pooled, Browns Creek displayed an overall density of utilizable species approximately nine times greater than that in San Carlos Creek. In Nichols Creek the estimated densities of utilizable species were generally somewhat higher than those in San Carlos Creek yet markedly lower than those

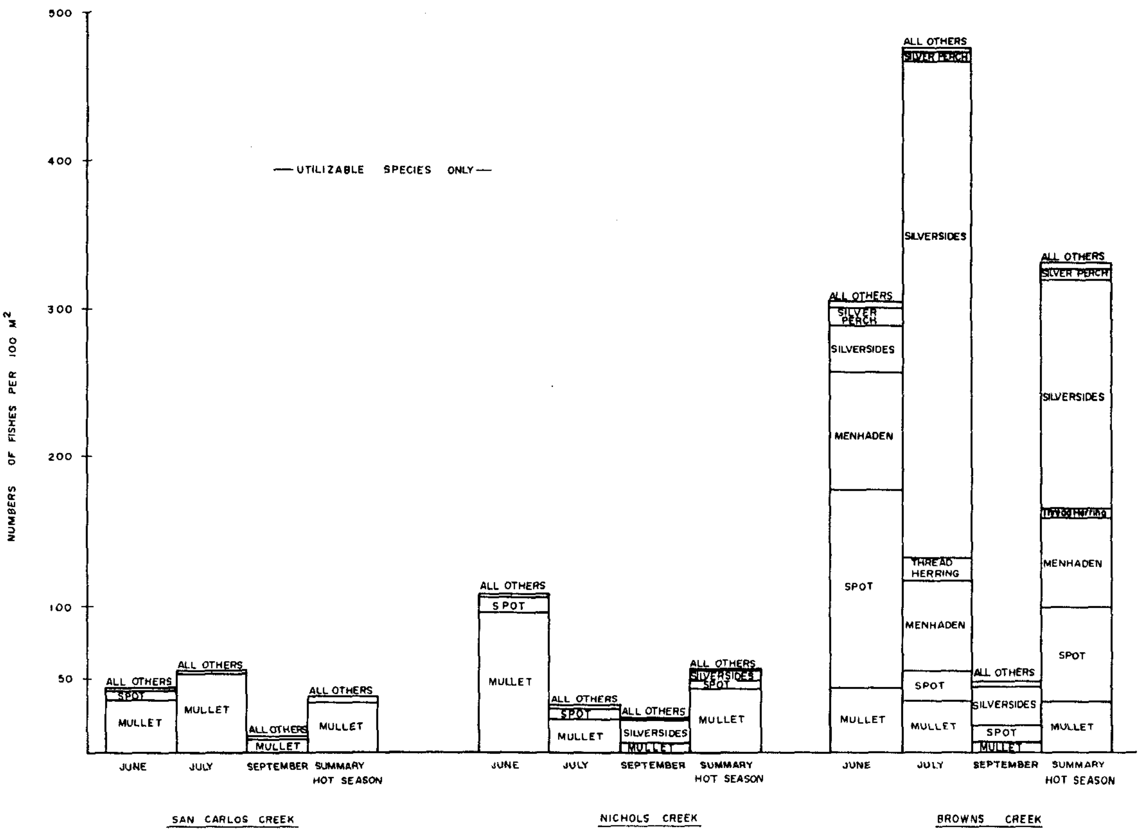


FIGURE 4.—Densities of utilizable species in the three creeks as estimated from seine collections. Histograms depicting "Summary Hot Season" compiled as described in Figure 3.

in Browns Creek. The injection of hot water that was forced through Nichols Creek twice each day (see Figure 2) obviously decreased the value of this second creek as a nursery area for utilizable species.

Figure 3 also illustrates the change in overall population structure that has occurred in response to the thermal effluent. Whereas in Browns Creek 61 to 79% (average 73.2%) of the total fishes in the monthly collections were utilizable species, in San Carlos Creek only 4 to 39% (average 19.4%) of the total specimens could be so categorized. Hence in contrast to the situation in the ambient temperature creek, the majority of the fishes occupying San Carlos Creek during the hot season are species not utilized by man. Dominant among this latter group of temperature tolerant fishes were two species of cyprinodonts (*Fundulus grandis* and *F. heteroclitus*) and the gerreid *Eucinostomous argenteus*. Whereas these three species alone accounted for 72% of the total fishes collected in San Carlos Creek, these same species accounted for only 16% of the total fishes collected in Browns Creek. In Nichols Creek the portion of the population consisting of utilizable species was generally greater than that in San Carlos Creek yet considerably less than that in Browns Creek.

Figure 4 illustrates the relative abundance of the various utilizable species collected in the three creeks. In San Carlos Creek, two species of mullet (*Mugil curema* and *M. cephalus*) alone accounted for 76 to 96% of the total utilizable species collected. In Browns Creek, mullet accounted for only 8 to 16% of the utilizable species. Five other species made major contributions to the array of utilizable species present in Browns Creek. These other species were (in order of decreasing abundance): tidewater silverside *Menidia beryllina*, spot *Leiostomus xanthurus*, Atlantic menhaden *Brevoortia tyrannus*, silver perch *Bairdiella chrysura*, and Atlantic thread herring *Opisthonema oglinum*. Silver perch *Bairdiella chrysura* were entirely absent from the San Carlos collections.

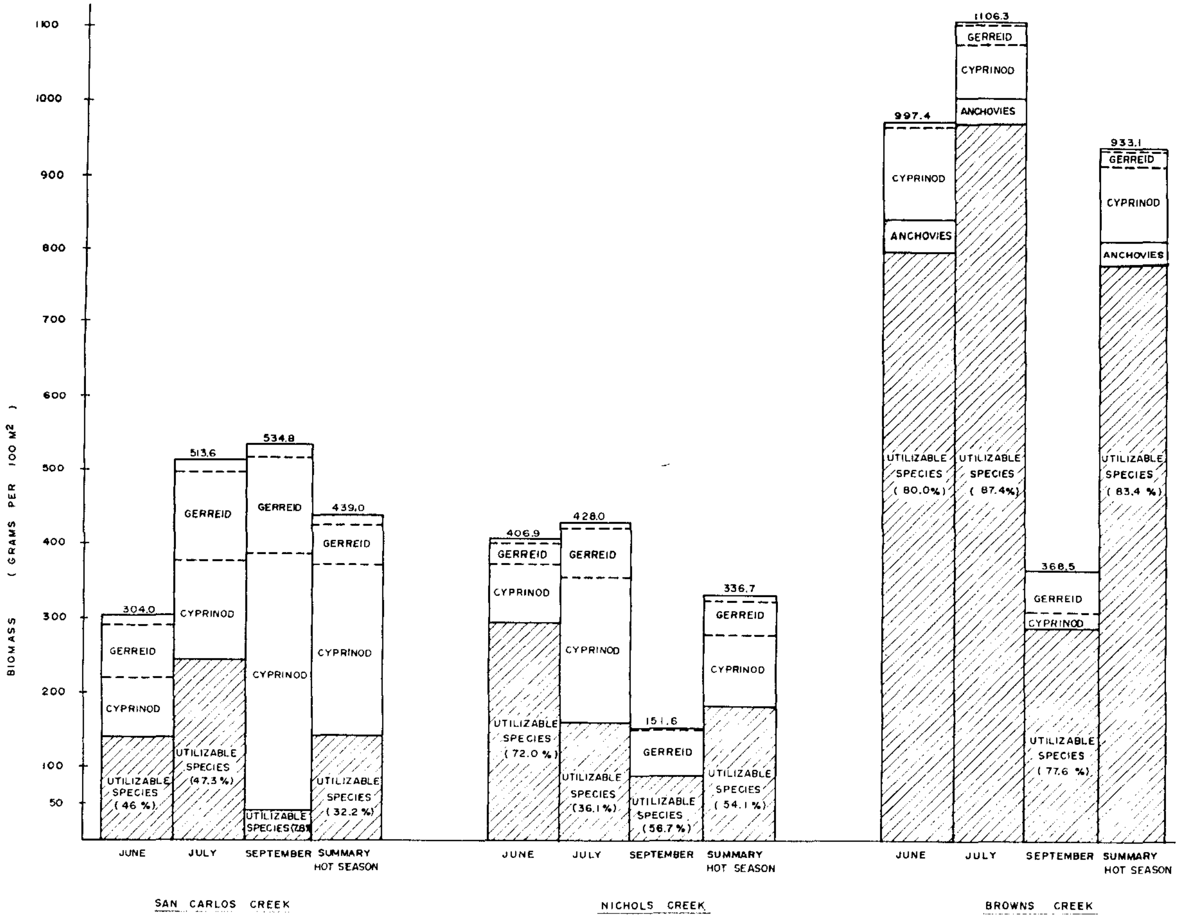


FIGURE 5.—Biomass per 100 m² of fishes in the three creeks as estimated from seine collections. Presentation as in Figure 3.

Figure 5 illustrates the biomass distributions that were computed from the weights of fishes obtained in the samples. The figure shows that the differences in overall standing crops (grams per 100 $m^2$) between the creeks conform quite closely to the differences in density described earlier. In June and July the estimated standing crop of total fishes in Browns Creek was approximately 2 to 3 times greater than that in San Carlos Creek and 2.5 times greater than that in Nichols Creek. In September, following the aforementioned emigration of juveniles of many transient species, the estimated standing crop in San Carlos Creek was 1.5 times greater than that in Browns Creek. However, even in September, Browns Creek continued to support a standing crop approximately 2.5 times greater than that in Nichols Creek.

Of greater significance than the overall differences in biomass described above, are the marked differences in utilizable species that existed between creeks. Throughout the entire collecting period, the biomass of utilizable species (grams per 100 $m^2$) was from four to seven times greater in Browns Creek than in San Carlos Creek and from three to six times greater in Browns Creek than in Nichols Creek. Whereas in Browns Creek the bulk of the biomass was distributed among utilizable species, in San Carlos Creek the bulk of the biomass was distributed among species not utilized by man. In San Carlos Creek, three species of nonutilized fishes (*F. grandis*, *F. heteroclitus*, and *E. argenteus*) accounted collectively for 45 to 85% (average 62%) of the total biomass. In Browns Creek these same species accounted for only 8 to 16% (average 11.9%) of the total biomass.

Figure 6 illustrates the biomass distributions among the various utilizable species. In San Carlos Creek, the two species of mullet alone accounted for 73 to 97% (average 86.7%) of the

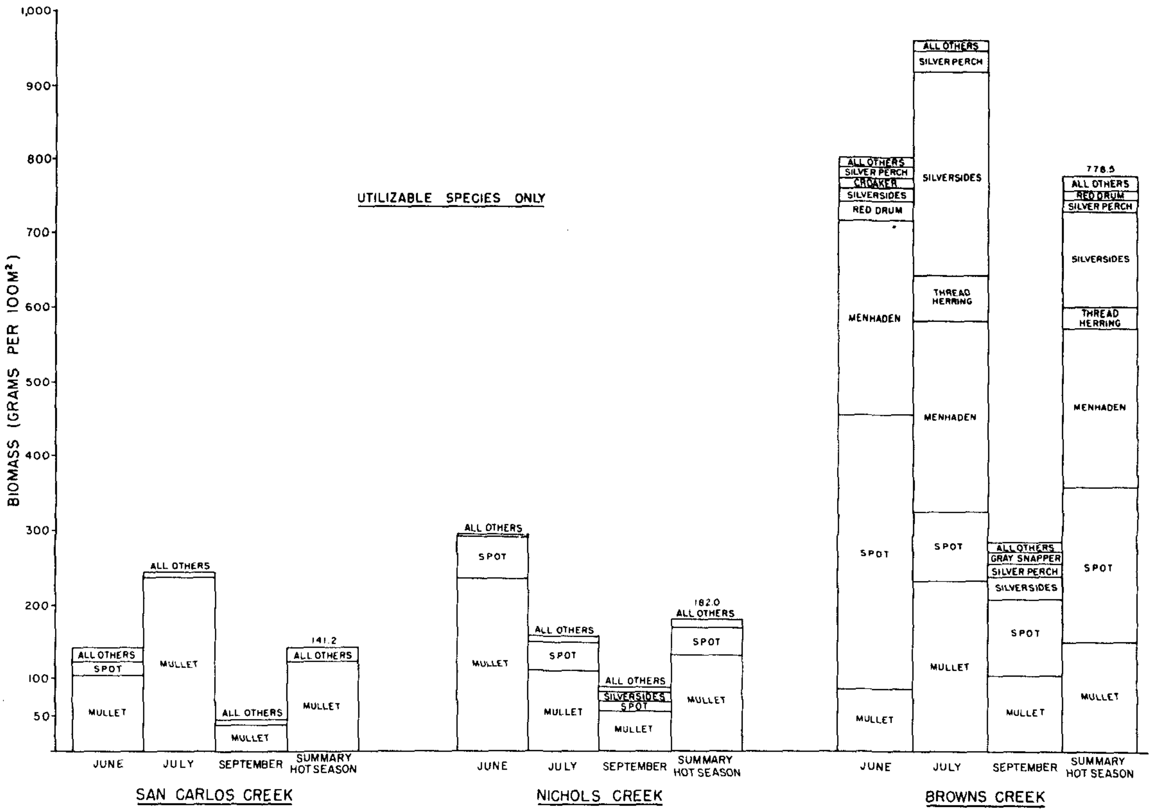


FIGURE 6.—Biomass per 100 m² of utilizable species in the three creeks as estimated from seine collections. Histograms depicting "Summary Hot Season" compiled as described in Figure 3.

biomass of utilizable species. In Browns Creek, the mullet accounted for only 11 to 37% (average 19.2%) of this biomass. The same five species that were cited earlier made the most significant additional contributions to the biomass of utilizable species in Browns Creek.

## DISCUSSION AND SUMMARY

Elevated water temperature resulting from the discharge of condenser cooling water by the two units of the Northside Generating Station in Jacksonville, Fla. has a detrimental effect on the capacity of two marshland creeks to serve as a nursery area for juvenile fishes during the hot season. Evidence for this detrimental effect is based upon the marked differences in both the density of fishes and the species composition which exist between an ambient temperature creek and two creeks receiving thermal effluent. To the best of our knowledge this is the first field study in which quantitative measurements have been reported on the effects of a thermal effluent on the capacity of an estuarine receiving water to continue serving as a nursery area for juvenile specimens, especially those of species having direct value to man. Although only the results of the 1973 study have been reported here, a preliminary, less-extensive study conducted at the same site in July and September of 1971 revealed the same basic types of differences that are described herein.

From the standpoint of coastal fisheries operations, the major detrimental effect of the thermal effluent is to decrease the suitability of the habitat for juveniles of species used by man as food and related fishery products. In the thermally affected creeks, both the numbers and the biomass of juveniles of utilizable species were 3- to 10-fold smaller than those encountered in the ambient temperature creek. Regarding these species, our data clearly show that whereas the creek receiving the largest input of thermal effluent affords a nursery habitat dominated almost entirely by mullet (primarily *Mugil curema*), the creek functioning at ambient temperature affords a nursery habitat for a much greater array of utilizable species. In both of the thermally affected creeks there was a marked diminution in the numbers and the biomass of the following seven species of utilizable fishes (listed in order of decreasing abundance in ambient temperature creek): tidewater silverside *Menidia beryllina*, spot *Leiostomus xanthurus*, Atlantic menhaden *Brevoortia tyrannus*, silver perch *Bairdiella chrysura*, Atlantic thread herring *Opisthonema oglinum*, Atlantic croaker *Micropogon undulatus*, and pinfish *Lagodon rhomboides*.

The shallow-water habitats afforded by marshland creeks are especially important to estuarine fishes during the hot season. As shown by McErlean et al. (1973), both the number of species and the number of individuals that rely on the shallow shore zone of the estuary are maximal in summer and spring. This is due in part to the time of spawning in many species, frequently in late winter or in the spring, and to the subsequent immigration into estuarine areas of juveniles of the many transient species. The September decline in both the number and the biomass of fishes that occurred in the ambient temperature creek (Browns Creek) is similar to the fall decline described by McErlean et al. for shallow-water stations in the Patuxent River.

In the review by Wurtz and Renn (1965) on water temperature and aquatic life, the following statements were made: "Although there are historic records of fish surviving natural temperatures of 100°F, this is unusual. Waters with temperatures that regularly exceed 95°F would not be expected to support a large, or diverse, fish population." It is noteworthy that throughout the period of this study, June through September, daily temperatures in San Carlos Creek routinely exceeded 95°F (35°C). In July and September, the average daytime temperatures recorded at all stations in this creek were, with but one exception, greater than 95°F (see Table 1). A maximum temperature of 102.6°F (39.2°C) was recorded at one station in July. Although the overall population of fishes found in San Carlos Creek was neither large nor very diverse, 15 species exhibited no marked diminution in numbers, and a few species were actually more abundant here than in the ambient temperature creek. Among the species of temperature tolerant fishes recorded in the current study, the gray snapper was reported by Nugent (1970) as being a species whose numbers were not diminished by the thermal effluent of a power plant situated to the south of Miami. Although the gray snapper was the most abundant species collected in the gill net samples reported by Nugent, it was a very minor member of the fish population sampled in our study. Nugent also reported that the tarpon, *Megalops atlantica*, was equally abundant at both heated and control stations. In the current study large tarpon were seen during midsummer within a few hundred yards of the outfall of the power plant in San Carlos Creek although no specimens were collected. Nugent reported a decrease in the numbers of white mullet (primarily adults taken by gill nets) at stations in the area of elevated temperature during the hot season. In the current study the estimated density of juvenile white mullet was quite similar in all of the creeks. Trembley (1961) reported that mummichogs from the Delaware River, acclimated to 32.2°C, had an $LD_{50}$ (mean lethal dose) of 39.4°C. If this $LD_{50}$ approximates that in our own study area then the presence of large numbers of this species in San Carlos Creek indicates that it is literally thriving in an environment in which the temperatures encountered daily during July are very close to the upper limits for survival.

The current study was directed primarily at an analysis of the effects of a thermal effluent and related conditions upon the population of juvenile fishes utilizing a nursery habitat during the hot season. It might be contended that the effects described herein for juvenile fishes do not necessarily apply to the population of adult fishes using the same heated creeks. However, de Silva (1969) surveyed literature relating to differential tolerances exhibited by both juveniles and adults of several species. He concluded that many juveniles appear to tolerate eurythermal conditions, while adults tend to be broadly stenothermal. If the above generalization is correct, then one would predict that the effect of the thermal effluent on the population of adult fishes would be even more extreme during the hot season than the effects we recorded regarding the juvenile fishes.

We recognize that some of the population changes ascribed to elevated water temperatures in the current study may be due in part to other factors operating in concert with temperature. As was pointed out by Mihursky and Kennedy (1967), temperature tolerance limits of aquatic organisms are affected by a number of other variables such as dissolved oxygen and carbon dioxide, salinity, and a variety of toxic substances. The St. Johns River in the vicinity of Jacksonville receives a multitude of pollutants in addition to thermal effluent. It is impossible to quantify the relative role played by other pollutants in altering the fish populations in the thermally affected creeks. However, since our control creek (Browns Creek) probably received the same array of extraneous pollutants from the river as did the heated creeks, it is possible to use the fish population found in Browns Creek as an indicator of how the system is faring without the addition of the thermal effluent and the various chemicals associated with power plant operation.

It is not the intent of this report to criticize the Northside Generating Station or the Jacksonville Electric Authority for the effects that the operation of their power plant is having upon the nursery area capacity of the adjacent marshland. It is realized that this plant is operating within the guidelines dictated by appropriate State and Federal agencies. Further, it is recognized that the acreage of marshland affected by this plant represents only a minute portion of the total marshland habitat available in this area. However, it is the intent of this report to show that massive discharges of thermal effluent do have a very obvious detrimental effect on the capacity of an estuarine receiving water to continue functioning as a nursery area for a variety of important species. This particular detrimental effect has received inadequate attention in the past. Since nursery areas represent one of our most valuable estuarine resources, it is imperative that this resource and its impairment should be given proper consideration during the site selection stages that precede the construction of future power plants.

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## LITERATURE CITED

BAILEY, R. M. (chairman).
1970. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc., Spec. Publ. 6, 150 p.

CARR, W. E. S., AND C. A. ADAMS.
1973. Food habits of juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River, Florida. Trans. Am. Fish. Soc. 102:511-540.

COUTANT, C. C.
1970. Thermal pollution—biological effects. A review of the literature of 1969. J. Water Pollut. Control Fed. 42:1025-1057.
1971. Thermal pollution—biological effects. A review of the literature of 1970. J. Water Pollut. Control Fed. 43:1292-1334.

DAHLBERG, M. D.
1970. Atlantic and Gulf of Mexico menhadens, Genus *Brevoortia* (Pisces:Clupeidae). Bull. Fla. State Mus., Biol. Sci. 15:91-162.

DE SILVA, D. P.
1969. Theoretical considerations of the effects of heated effluents on marine fishes. *In* P. A. Krenkel and F. L. Parker (editors), Biological aspects of thermal pollution, p. 229-293. Vanderbilt Univ. Press, Nashville.

GRIMES, C. B.
1971. Thermal addition studies of the Crystal River steam electric station. Fla. Dep. Nat. Resour. Mar. Res. Lab., Prof. Pap. Ser. 11, 53 p.

GRIMES, C. B., AND J. A. MOUNTAIN.
1971. Effects of thermal effluent upon marine fishes near the Crystal River steam electric station. Fla. Dep. Nat. Resour. Mar. Res. Lab., Prof. Pap. Ser. 17, 64 p.

JENSEN, L. D., R. M. DAVIES, A. S. BROOKS, AND C. D. MEYERS.
1969. The effects of elevated temperature upon aquatic invertebrates. The Johns Hopkins Univ. Cooling Water Studies for Edison Electric Inst. RP-49, Rep. No. 4, 232 p.

KRENKEL, P. A., AND F. L. PARKER.
1969. Engineering aspects, sources, and magnitude of thermal pollution. *In* P. A. Krenkel and F. L. Parker (editors), Biological aspects of thermal pollution, p. 10-61. Vanderbilt Univ. Press, Nashville.

LYLES, C. H.
1969. Fishery statistics of the United States, 1967. U.S. Fish Wildl. Serv., Stat. Dig. 61, 490 p.

MCERLEAN, A. J., S. G. O'CONNOR, J. A. MIHURSKY, AND C. I. GIBSON.
1973. Abundance, diversity and seasonal patterns of estuarine fish populations. Estuarine Coastal Mar. Sci. 1:19-36.

MIHURSKY, J. A., AND V. S. KENNEDY.
1967. Water temperature criteria to protect aquatic life. *In* E. L. Cooper (editor), A symposium on water quality criteria to protect aquatic life. Am. Fish. Soc., Spec. Publ. 4, p. 20-32.

NAYLOR, E.
1965. Effects of heated effluents upon marine and estuarine organisms. Adv. Mar. Biol. 3:63-103.

NUGENT, R. S., JR.
1970. The effects of thermal effluent on some of the macrofauna of a subtropical estuary. Ph.D. Thesis, Univ. Miami, Miami, 210 p.

SCHELSKE, C. L., AND E. P. ODUM.
1961. Mechanisms maintaining high productivity in Georgia estuaries. Proc. 14th Annu. Sess., Gulf Caribb. Fish. Inst., p. 75-80.

SKUD, B. E., AND W. B. WILSON.
1960. Role of estuarine waters in Gulf fisheries. Trans. 25th North Am. Wildl. Conf., p. 320-326.

SMITH, R. F., A. H. SWARTZ, AND W. H. MASSMANN (editors).
1966. A symposium on estuarine fisheries. Am. Fish. Soc., Spec. Publ. 3, 154 p.

SYKES, J. E., AND J. H. FINUCANE.
1966. Occurrence in Tampa Bay, Florida, of immature species dominant in Gulf of Mexico commercial fisheries. U.S. Fish Wildl. Serv., Fish. Bull. 65:369-379.

SYLVESTER, J. R.
1972. Possible effects of thermal effluents on fish: A review. Environ. Pollut. 3:205-215.

TREMBLEY, F. J.
1961. Research project on effects of condenser discharge water on aquatic life. Prog. Rep. 1960. Inst. Res., Lehigh Univ., 80 p.

WURTZ, C. B., AND C. E. RENN.
1965. Water temperatures and aquatic life. The Johns Hopkins Univ. Cooling Water Studies for Edison Electric Inst. RP-49, Rep. No. 1, 99 p.