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Seasonal changes in the reproductive condition and body composition of free-ranging red drum, *Sciaenops ocellatus*

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Abstract

Adult red drum (*Sciaenops ocellatus*) from a wild, autumn (fall) spawning population were studied over a 1-year period to evaluate seasonal changes in body composition in comparison with cultured red drum. Each month, female and male fish were captured and blood sampled. Standard length and weight were measured, and gonads, liver, intraperitoneal fat (IPF), and a sample of muscle tissue were collected from each fish. Gonadosomatic index (GSI), hepatosomatic index (HSI), IPF ratio, protein and lipid composition of muscle and liver tissues, and lipid class composition of liver samples were determined for each fish. All tissue indices exhibited a similar seasonal cycle in both sexes, with highest HSI in spring (March–April) and maximal IPF ratio in May, followed in September and October by minimal values for HSI and IPF ratio. Whereas GSI was low, gonadal histology demonstrated activation of spermatogenesis and oocyte development in July and August. Liver composition varied dramatically throughout the year. Liver lipid content ranged from 7.4% of wet weight in November to 30.2% in August, with triglycerides (TG) being the most abundant component at all times. Liver protein was more stable, ranging from 11.5% in August to 16.3% in September. Muscle composition was relatively constant, with muscle crude protein ranging from 20.5% to 25.6% of wet weight and muscle lipid ranging from 0.4% to 2.2%

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of wet weight. These data indicate that red drum utilize the liver as a major depot for lipid. Depletion of maximal lipid reserves from liver and IPF in late summer indicates that lipid stored during active spring and summer feeding supplies energy for reproduction which is mobilized rapidly (within 1 month) in this fall-spawning species. Body composition of wild fish is similar to that of laboratory cultured red drum. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Red drum; *Sciaenidae*; Body composition; Seasonal; Reproduction; Liver; Muscle

1. Introduction

Wild temperate fish undergo seasonal changes in growth and energy storage (Hardy and Keay, 1972; Dygert, 1990; Montgomery and Galzin, 1993; Jorgensen et al., 1997) as energy from diet and body reserves is partitioned between maintenance, somatic growth, and reproduction (Brett and Groves, 1979; Nelson and McPherson, 1987; Smith et al., 1990). During somatic growth, lipid, protein and ash are typically accumulated while protein and lipid are depleted during gonadal growth (Tanasichuk and Mackay, 1989; Dygert, 1990; Jorgensen et al., 1997). Similar changes in body composition can be elicited in cultured fish through manipulation of dietary and environmental conditions (Shearer, 1994). Although it is preferable for fish in aquacultural situations to be marketed before reaching sexual maturity (Reay, 1984), considerable information can be obtained from the study of annual cycles in their adult wild counterparts. Data from wild animals provide baseline information on body composition, which is useful in evaluating the quality and physiological condition of cultured animals. Additionally, knowledge of annual cycles in wild fish can elucidate environmental and physiological controls of growth and nutrient utilization that may aid in the enhancement of growth or final product quality in cultured animals.

Since interest in the culture of red drum (*Sciaenops ocellatus*) began in the middle 1970s, basic research into optimizing environmental and nutritional conditions for production of this species has been intense (Thomas and Arnold, 1993; Gatlin, 1995). This research has resulted in increased commercial production of red drum throughout the southeastern United States. As nutritional information on red drum accumulates, the need for a basic understanding of the metabolic schemes employed by this species becomes more apparent. Although controlled spawning and larval rearing of red drum have become somewhat reliable in the industry, characterization of the annual reproductive and compositional cycles of this species in the wild has been limited because of difficulties in routinely capturing wild adult red drum on the consistent month-to-month basis necessary to conduct a meaningful seasonal study. Prior studies of reproductive cyclicity (Murphy and Taylor, 1990; Wilson and Nieland, 1994) relied heavily on a now discontinued commercial fishery as a source of red drum; few locations exist where sufficient numbers of adult animals can be predictably collected throughout the year for a meaningful physiological study. The Dow Chemical plant located in Freeport, TX, thus provides a unique opportunity for a seasonal study of red drum. The plant is connected to the Gulf of Mexico by a 10-km long intake canal, which supplies up to 4 million liters of seawater daily. The canal is open to the Gulf, allowing wild animals free

access. At the entrance to the plant, the intake water is screened of smaller fish and crustaceans which are returned to the canal, making this point a congregation area for predators looking for food. This location attracts red drum throughout the year in numbers which are sufficient for seasonal studies.

We characterized this population by describing seasonal patterns in reproductive condition and establishing normal ranges for annual changes in body composition. This seasonal study establishes that this population reflects the reproductive cyclicity previously reported for this species in the Gulf of Mexico, and provides comparative data for cultured red drum, which may serve as the basis for further studies of the physiological regulation of body composition.

2. Materials and methods

Adult red drum were captured monthly by hook and line at the Dow Chemical plant in Freeport, TX. Angling time to retrieve a fish was generally less than 5 min, and often less than 1 min. These fish were wild animals inhabiting a dredged, seawater intake canal, which ran from the Gulf of Mexico into the Dow facility. Each month (with the exception of December and January, when no fish were captured under windy and cold conditions, water $T = 14$°C), up to eight female and eight male red drum (Fig. 1) were captured in 1 day between 1600 and 2200 h, bled via venipuncture of the caudal vein, and euthanized by a blow to the head. Standard length and weight of each fish were measured. When possible, animals were selected for lengths between 60 and 80 cm. Each fish was dissected to remove the liver, gonads, and a sample of muscle tissue from below the first dorsal spine. Beginning in March, gonads and intraperitoneal fat (IPF) were also collected. Weights of the gonads, liver, and IPF were recorded for the determination of a gonadosomatic index (GSI), hepatosomatic index (HSI), and IPF ratio for each fish. These indices were calculated as follows: GSI = total gonadal weight × 100/total fish weight; HSI = liver weight × 100/total fish weight; and IPF ratio = total IPF weight × 100/total fish weight. Equivalently sized red drum (seven females and six males) approximately 5 years old which were laboratory-spawned, raised, and held as brood fish were blood sampled, killed, and analyzed at 1400 h in November in the same manner as the wild fish to allow for a comparison between wild and laboratory-reared adult red drum. These captive brood fish were being held at the University of Texas Marine Science Institute (UTMSI) in Port Aransas, TX, in a 12 000-l circular tank with water temperatures ranging from 26–28°C and a photoperiod of 12 h light: 12 h dark (conditions simulating the fall spawning season). During the prior 12 months, they had been maintained on a daily diet of squid and shrimp, and exposed to a compressed (6 months) annual photoperiod and temperature cycle to stimulate spawning activity.

Liver and muscle samples were frozen at −80°C until analysis, while gonads were fixed in 2% glutaraldehyde and prepared for light microscopy as described by MacKenzie et al. (1989). Samples of liver and muscle tissue were homogenized and analyzed for proximate composition, including moisture, dry matter, crude protein (AOAC, 1984) and total lipid (Folch et al., 1957). All composition data are expressed as g/100 g wet weight of tissue. Additionally, liver lipid samples for wild animals were analyzed for

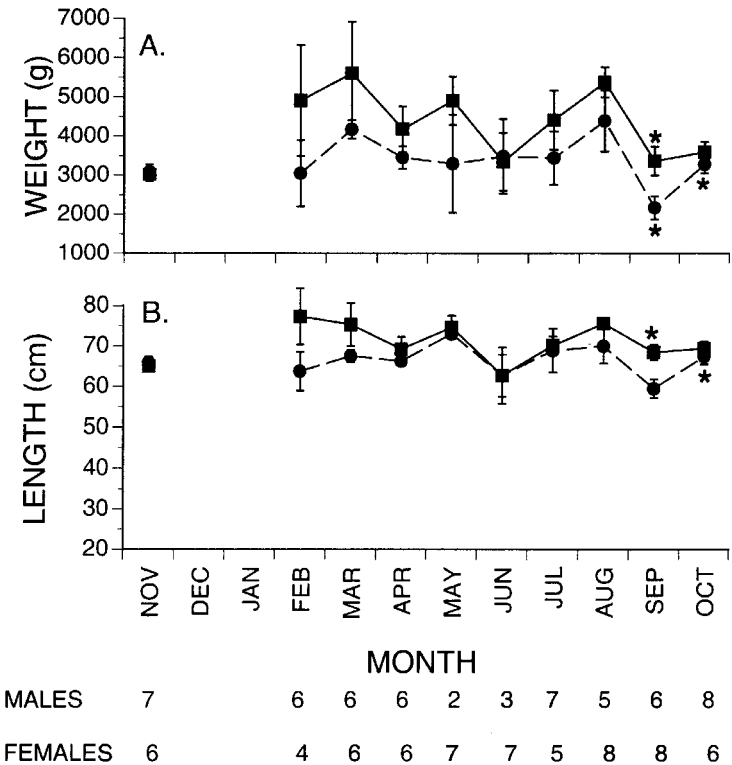

Fig. 1. Monthly changes in (A) body weight and (B) standard length of red drum. Values are means ± standard error for females (squares, solid line) and males (circles, dashed line). Numbers of fish collected each month are indicated at the bottom of the graph. Asterisk designates mean, which are significantly different from the mean for the same sex from the preceding month.

lipid composition utilizing the IatroScan TLC-FID system (Bioscan, Washington, DC). Using this methodology, the following lipid classes were quantified in liver tissue: cholesterol esters (CE), triglycerides (TG), free fatty acids (FFA), cholesterol (CHOL) and phospholipids (PL). Duplicate samples from each fish of the same sex were combined for a monthly mean for each analysis.

For all data, males and females were analyzed separately by analysis of variance utilizing the General Linear Models (GLM) procedure of the SAS program package (SAS Institute, 1985), coupled with Duncan's multiple range test for comparisons of means by month. When parametric assumptions were not met, data were analyzed using the NPAR1WAY procedure, with paired comparisons of consecutive monthly means made using a Wilcoxon test. For all statistical tests, significance was set at $p < 0.05$.

3. Results

Red drum collected in the present study ranged in size from 60 to 77 cm in mean standard length and 2.2 to 5.6 kg in mean total weight (Fig. 1A and B). No obvious

trends in length or weight were apparent over the sampling year, although weight in both sexes decreased significantly from August to September. Water temperatures were fairly constant at 28–30°C from April to October, following temperatures of 15–20°C prior to April.

3.1. Biological indices

No significant differences existed in male GSI values of wild animals. Wild male GSI ranged from 0.02% to 0.06% except in August, when 0.4 % was the highest value observed for males in this study. From November through July, testes were pale and threadlike. Histological examination showed regressed, inactive tubules from November through March. Spermatogonial proliferation (Stage I of Grier, 1981) was first observed in tubules in March, and continued through June. A male with externally expressible milt was first observed in July. This male, and one other in July (of eight males captured) demonstrated histologically all stages of spermatogenesis (Stage III of Grier, 1981). Only 3 of the 19 males captured during July, August, and September had expressible milt. However, all males captured in August and two of six males in September showed active spermatogenesis (Stages II to V of Grier, 1981), and two September males had testes which appeared histologically to be post-spawning (few remaining cysts, open tubules with few spermatozoa, Stage VI of Grier, 1981). In

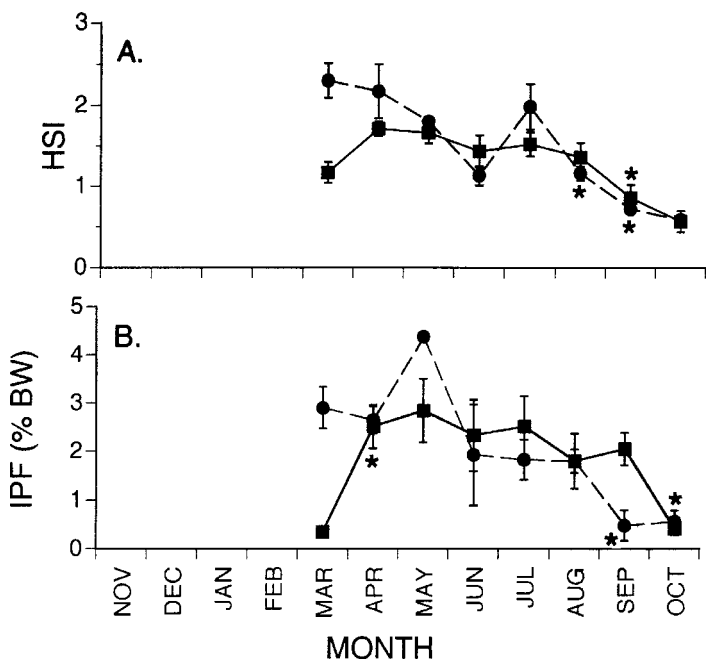

Fig. 2. Monthly changes in (A) HSI and (B) IPF ratio (expressed as percent of body weight) of red drum. Values are means ± standard error for females (squares, solid line) and males (circles, dashed line). Asterisk designates mean, which are significantly different from the mean for the same sex from the preceding month.

October, testes were regressed. Captive male brood fish had a GSI of 2.25%, and were actively spermiating with expressible milt.

A similar trend was observed in females. No significant differences were observed in wild female GSI. Highest mean GSI (1.0%) was observed in August, with values in other months ranging from 0.2% to 0.3%. From November through June, ovaries were small and pale. Histological examination showed exclusively primary oocytes less than 0.1 mm in diameter. More vascularized ovaries were first observed in late July, when two of eight females sampled showed a few (less than 10%) oocytes in the cortical granule stage (Wallace and Selman, 1981), less than 0.2 mm in diameter. Of eight females captured in August, four showed ovaries comprised of primary oocytes, two had ovaries advanced to the cortical granule stage, and two exhibited vitellogenesis (mean GSI 2.2), with oocyte diameters up to 0.5 mm. One additional female in vitellogenesis (up to 0.5 mm diameter) was captured in September. The remainder of the September and October females were all at the primary oocyte stage. No atretic or post-ovulatory follicles were observed. The cultured female brood fish showed the highest GSI of 4.4%. Captive females had developed ovaries with abundant vitellogenic oocytes.

Liver size of red drum varied significantly (Fig. 2A). The HSI in males ranged from a high of 2.3 in March to 0.6 in October, generally declining steadily over this time with the exception of a peak in July. Females, like males, had the lowest value for HSI in October and higher, relatively constant values in the spring. The HSI for the cultured

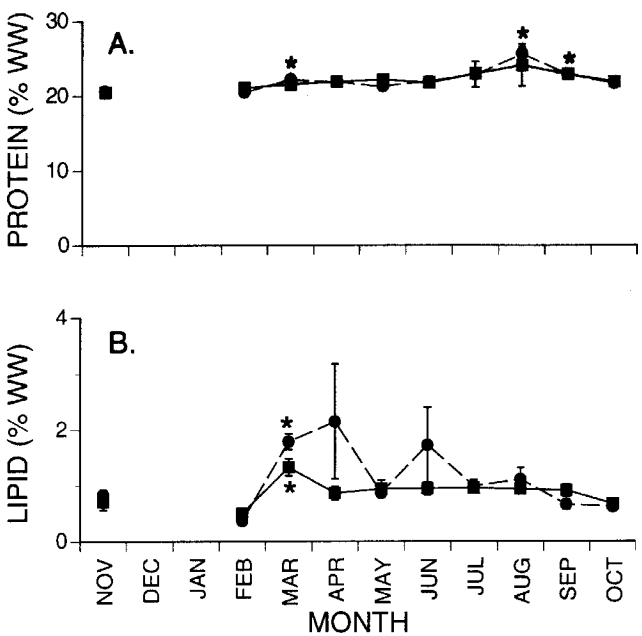

Fig. 3. Monthly changes in (A) muscle protein and (B) muscle lipid of red drum. Values are expressed as means of percent wet weight (WW) ± standard error for females (squares, solid line) and males (circles, dashed line). Asterisk designates mean, which are significantly different from the mean for the same sex from the preceding month.

brood fish was 0.7 (SEM = 0.1) for males and 0.9 (0.1) for females, equivalent to the lowest values for wild fish.

IPF ratio values of male and female red drum followed a similar pattern, demonstrating significant variation (Fig. 2B). The IPF ratio was highest in males in spring (March, April, and May), declining significantly after August to the lowest values in September and October. Female red drum showed a significant increase in IPF ratio from March to April, and maintained elevated levels until September, when IPF again dropped significantly to low levels equivalent to those observed in March. Cultured brood fish had intermediate mean IPF ratio values relative to wild fish at 1.3 (0.5) for males and 0.9 (0.1) for females.

Muscle protein values (Fig. 3A) in male fish ranged from a low of 20.5% of wet weight in February to a high of 25.6% in August. Muscle protein was generally stable. Muscle protein in the cultured brood fish was 24.0% (0.2) for males and 23.7% (0.4) in females, within the range for wild fish. Muscle lipid increased significantly in both sexes between February and March. Muscle lipid in males was variable throughout the remainder of the year, settling to low levels in fall (Fig. 3B). Female red drum had relatively stable muscle lipid levels, with highest values in March and relatively steady values in the summer months. The cultured brood fish had muscle lipid levels of 0.8% (0.1) for both males and females.

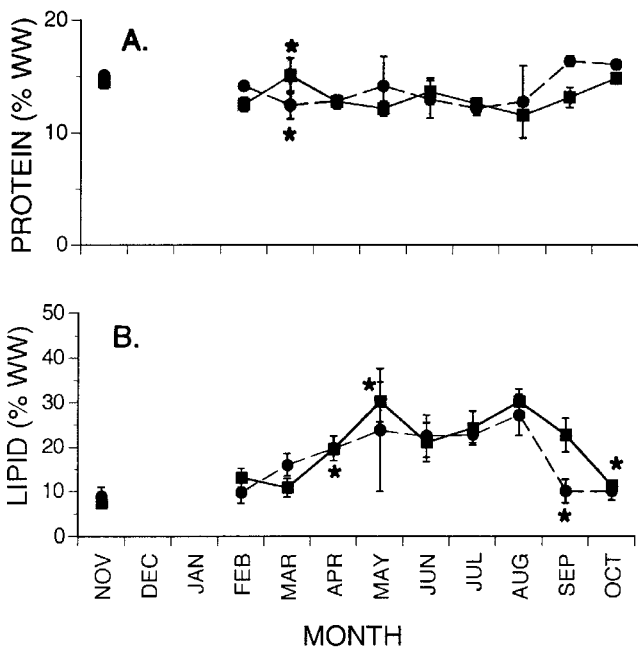

Fig. 4. Monthly changes in (A) liver protein and (B) liver lipid of red drum. Values are expressed as means of percent wet weight (WW) ± standard error for females (squares, solid line) and males (circles, dashed line). Asterisk designates mean, which are significantly different from the mean for the same sex from the preceding month.

Liver protein (Fig. 4A) in both sexes of wild red drum was generally stable between 11.5% and 16.3%. Liver protein in the cultured brood fish was 13.4% (0.3) in males and 14.9% (0.8) in females. In both sexes, liver lipid (Fig. 4B) showed the greatest magnitude change of any tissue component. Lipid levels rose during the spring with the highest liver lipid in male red drum observed in the summer months of May, June, July and August, dropping in September, October, and November. Liver lipid in females was also highest in the summer months, declining in September and October. The cultured brood fish had liver lipid values of 18.6% (2.2) in males and 13.4% (3.0) in females.

Male liver lipid was predominantly composed of TG, declining from highest levels in August to lowest in October (Table 1). FFA were the next most abundant constituent of liver lipid, similarly with highest levels in summer and lowest values in October. In male fish, PL, CHOL, and CE levels varied throughout the year over relatively small ranges. Female red drum exhibited similar liver lipid composition (Table 1). As in male

Table 1
Lipid classes in total lipid fractions of liver tissue from red drum. Values are means (with standard errors) in μg/g liver tissue

Month	*n*	CE	TG	FFA	CHOL	PL
Males						
April	2	8.5	69.5	11.7	6.1	1.9
		–	–	–	–	–
May	2	5.4	108.6	6.6	3.4	1.9
		(4.5)	(70.9)	(1.6)	(2.5)	(2.6)
June	3	4.5	113.3	23.4	4.0	11.6
		(1.5)	(58.6)	(10.3)	(1.4)	(4.0)
July	8	5.6	163.3	12.1	5.3	5.4
		(1.7)	(41.3)	(3.3)	(1.4)	(1.9)
August	5	9.2	182.8	15.9	3.3	17.6
		(6.3)	(89.7)	(2.4)	(1.2)	(5.1)
September	6	3.4	67.0	16.3	1.9	8.1
		(2.2)	(68.7)	(14.3)	(1.2)	(4.1)
October	8	2.5	53.7	5.6	1.4	5.6
		(2.0)	(42.3)	(1.6)	(0.9)	(3.1)
Females						
April	2	8.6	116.9	27.0	4.5	3.9
		–	–	–	–	–
June	7	5.5	119.3	18.2	4.3	9.4
		(3.5)	(75.3)	(9.7)	(2.9)	(5.1)
July	9	8.3	175.3	10.7	4.0	9.7
		(5.3)	(90.7)	(2.6)	(2.2)	(8.3)
August	9	15.1	207.0	16.3	4.2	17.5
		(8.8)	(69.4)	(4.7)	(2.5)	(7.8)
September	7	7.8	145.5	22.4	4.8	13.4
		(5.6)	(68.2)	(14.4)	(1.9)	(7.4)
October	6	3.4	39.6	10.5	0.7	6.3
		(5.4)	(13.0)	(1.8)	(0.6)	(3.6)

CE = cholesterol esters; TG = triglycerides; FFA = free fatty acids; CHOL = cholesterol; PL = phospholipids.

fish, liver lipid in female fish was composed primarily of TG, which was greatest in August and minimal in October. FFA, PL, CE and CHOL levels were substantially lower and relatively stable.

4. Discussion

Red drum collected during the first 9 months of this study were relatively large specimens, ranging from 2.2 to 5.4 kg in weight. Both the size and the timing of reproductive development in these animals suggest that the majority were reproductively active adults. Adult red drum spawn from August through January with peak spawning activity from September through October in Texas (Matlock, 1984). Spawning appears to occur in the nearshore Gulf, adjacent to bay-gulf passes through which larvae are dispersed into estuarine nurseries. Although precocious spawning of red drum in the laboratory at an age of only 19.5 months and a weight of 2.9 kg has been achieved (Arnold, 1991), the growth rate in nature is probably much slower and maturation is believed to take from 3 to 5 years (Matlock, 1984, 1987; Murphy and Taylor, 1990; Wilson and Nieland, 1994). The fish captured in the present study correspond to a size at which wild red drum are 4–5 years old and at which 50–100% of wild animals sampled from Galveston Bay (less than 50 km from our sampling site) to Alabama (Wilson and Nieland, 1994) or in Florida Gulf waters (Murphy and Taylor, 1990) were reported to be sexually mature.

In the present study, evidence for testicular recrudescence (proliferation of spermatogonia) was first observed in March, with the first spermiating male observed in July. Wilson and Nieland (1994) found that wild male GSI increased in July, but suggested that histological examination is preferable to other methodologies in assessing gonadal development of red drum. Our histological examination indicates that initiation of testicular development preceded detectable GSI increases. Initiation of oocyte development (appearance of oocytes containing cortical alveoli) was first observed in July, yet very few females undergoing vitellogenesis were observed. Whereas GSI was low for females, the histological observation indicated gonadal development consistent with preparation for spawning observed in other wild populations (Murphy and Taylor, 1990; Wilson and Nieland, 1994), including oocyte diameters (0.5 mm) equivalent to maximum mean values observed in Florida populations (Murphy and Taylor, 1990). Only five female red drum were collected with oocytes at this diameter, four in August and one in September. This suggests that these fish were preparing to participate in spawning during the peak period, and that the process of vitellogenesis occurs within 1 to 3 months in the red drum collected in the present study, as has been noted in other populations of red drum (Wilson and Nieland, 1994). In September, no vitellogenic female fish were collected and only one of the males collected was spermiating. Since animals must move from feeding grounds to spawning areas at this time, it is suggested that the scarcity of fish with mature ovaries in September indicates that they had migrated from the canal to the bay passes of the Gulf to join the spawning population. These fish may therefore initiate, but not conclude, their gonadal development in the canals where they were collected. It is also possible that a distinct population of younger

fish remaining in the canal were captured in September when the mature fish had migrated to the Gulf, as red drum of both sexes collected in September weighed approximately 50% less than those collected in August and were reproductively heterogeneous. The larger males in September appeared to have completed spawning activity, whereas the smaller, regressed males may have represented younger fish, which did not participate in spawning.

Previous studies of the relationship between body lipid and reproductive activity have focused primarily on species which spawn in spring or early summer. In the present study, actively-feeding red drum were captured in the months immediately preceding fall spawning, providing an opportunity to determine if the activation of reproductive effort significantly impacted major lipid reserves in feeding animals. Red drum accumulated liver lipid and IPF during active feeding in the summer. The significant decline in IPF and liver lipid observed from July to October in both males and females suggests that energy and nutrients are mobilized from IPF and liver to support reproductive development and spawning in larger fish. Such changes have typically been observed prior to spawning in other species (Tanasichuk and Mackay, 1989; Dygert, 1990; Jorgensen et al., 1997). However, failure to observe postovulatory or atretic follicles in females captured in September and October suggests that, in spite of their size, these animals may not have participated in spawning. Observed declines in lipid storage in fall samples may therefore represent a combination of energy utilization for reproductive effort and active growth at a time of maximal water temperatures.

Body composition of fish is well known to change in response to environmental conditions and season (Tanasichuk and Mackay, 1989; Dygert, 1990). In the present study, body composition varied significantly with respect to month. These changes were more evident in liver tissue, particularly with lipid, as compared to muscle of wild red drum. Apparently, red drum make little use of muscle tissue as a depot for lipid, as muscle lipid was relatively insensitive to seasonal influences. In contrast, the liver of wild red drum is a dynamic depot, exhibiting a pronounced seasonal cycle in lipid levels. Liver lipid in wild red drum was over 200% higher in the summer months than in February or October, presumably reflecting energy storage during times of active feeding and maximum somatic growth. The area from which these fish were collected had an abundance of prey organisms throughout the summer months and the hook and line method of collection insured that collected fish were actively feeding. The elevated lipid levels throughout the summer indicate that the liver serves as the major lipid depot in wild red drum. The high lipid levels observed in the wild fish of both sexes during the summer months could be indicative of increased lipid biosynthesis in the liver to provide an energy reserve that could be utilized for somatic or reproductive growth.

Liver lipid class information supports this storage role for the liver, as TG, the primary storage form of lipids in teleosts (Sheridan, 1988), were the dominant component of lipid extracted from liver tissue. In both sexes of fish captured in August, the values observed for CE, TG, and PL were the highest for each respective class during the entire study, indicating that lipid storage is activated during the summer months. The large range observed for TG suggests further that it is mobilized seasonally, possibly for vitellogenin synthesis or energy for migration and spawning activity. There were no apparent trends in values for FFA or CHOL over the course of the study.

Of most importance in aquaculture are the patterns of lipid deposition in the liver and peritoneal cavity. The excess accumulation of lipid in the liver of cultured red drum has been a concern to the industry as it is thought to reflect excess energy in diets, which are not efficiently utilized for production. Wild fish in this study had high lipid levels in the liver throughout the summer months, and captive brood fish showed muscle and liver lipid levels that were within the range observed for wild animals. The dramatic effects diet composition can have on body composition make comparisons between the wild fish and cultured red drum difficult because the diet of the wild fish was unknown in terms of composition and rate of consumption. It is thus surprising that the body composition of wild and cultured animals was so similar, given the presumed differences in age, activity, and food consumption. It also appears as if cultured juvenile red drum utilized in feeding trials in prior studies have body compositions quite similar to those observed in the wild fish during the summer months (Moon and Gatlin, 1994; Craig and Gatlin, 1995; Craig et al., 1995). This would presumably be a comparison at the time of most rapid growth for both groups of fish. Additionally, if the liver serves as the major depot and biosynthetic center for lipid during times of rapid growth, the relatively low liver lipid observed in the cultured brood fish may represent fish which are increasing lipid mobilization from this depot to support reproductive effort. Comparison of wild and domestic fish thus demonstrates that although livers of cultured red drum are perceived to be excessively fatty, lipid levels in both juveniles and adults are comparable to those found in actively feeding wild populations in the summer.

Excessive deposition of lipid in the peritoneal cavity represents wasted energy from an aquacultural standpoint, because there is no need to build a reserve for future mobilization, and this has important significance in the commercial culture of red drum in terms of efficiently regulating dietary input for optimal growth, while maximizing the dress-out weight of the final product. The IPF ratio values observed in wild fish were generally higher than those observed in cultured juvenile red drum. Although in some instances IPF ratios of juvenile fish have been above 2.5 (Moon and Gatlin, 1994; Moon et al., 1994), in the majority of cases, IPF ratio values range from 0 to 1.0 in cultured red drum (Craig and Gatlin, 1995; Craig et al., 1995). This could be indicative of a decrease in deposition due to a greater need for energy during the juvenile stage of the life cycle. However, certain diets (commercial as well as experimental) are more prone to cause excessive lipid deposition in the peritoneal cavity of red drum (Moon and Gatlin, 1994; Moon et al., 1994; Craig and Gatlin, 1995; Craig et al., 1995). Additionally, the wild fish in this study may have increased lipid storage in the peritoneal cavity for times of reduced food availability or for the increased energy demands of reproduction. This was apparent in the decline in IPF ratio observed in both sexes from August to October. The IPF ratio values were generally reduced in the cultured brood fish relative to those observed in the wild fish, another possible indication of lipid mobilization in the cultured fish to supply energy needed for reproduction.

Regulation of lipid metabolism in red drum could come from many sources. Feeding rate and activity have dramatic impacts on lipid deposition and/or mobilization, as do water temperature and other environmental factors (Sheridan, 1988). Water temperatures were generally constant from April to October, only ranging from 28–30°C. This relatively warm water temperature could result in higher metabolic rates and thus higher

feeding rates to meet these increased metabolic demands. Hormonal activity is responsive to environmental and dietary manipulations, and has dramatic effects on metabolic activity in general, with hormones such as triiodothyronine and reproductive steroids having specific effects on lipid metabolism (Sheridan, 1988; MacKenzie et al., 1998). A comparison between the cultured brood fish and the wild fish collected in August illustrates the potential effects of reproductive hormones on body composition. The cultured brood fish and the wild fish collected in August had very similar muscle protein and lipid composition. However, there were interesting differences in liver protein and lipid. Compared to the wild fish, liver protein in the cultured brood fish was 5% higher in males, but 29% higher in females. Liver lipid was significantly lower in both sexes of the cultured brood fish: in females, the liver lipid was 44% of wild levels in the cultured brood fish, whereas it was 68% of wild levels in the males. These brood fish were maintained on a diet of shrimp and squid, a diet not unlike the natural diet of wild red drum, although the feeding rate in the captive fish was probably higher than that experienced in nature by wild fish. However, these fish were also being held in spawning condition under photoperiod and temperature manipulation, and this lower liver lipid and increased liver protein could be an indication of lipid mobilization to the ovaries during vitellogenesis to rebuild the gonads for the next spawn.

This study indicates that the liver is a major biosynthetic and depot organ for lipid in red drum. Wild red drum, as well as cultured juveniles, have relatively fatty livers when compared to other fish, up to 30% on a wet weight basis. High lipid in liver of red drum does not appear to adversely affect this species, as the fish collected in this study were extremely robust and healthy-looking specimens. This high level of hepatic lipid is consistent with other studies, which have shown that the life history of species can affect the way lipid is stored in the body. For example, demersal fish such as red drum and cod tend to store lipid primarily in their livers, while pelagic species such as herring or mackerel tend to store high levels of lipid in the muscle (Sheridan, 1988; Sargent, 1997). These data also show that red drum do not experience drastic variations in protein or lipid content of muscle during spawning, often observed in other fish species which undergo hypophagia during their spawning season (Nelson and McPherson, 1987; Meefe and Snelson, 1993). The relatively high lipid storage associated with the livers of adult red drum appears to be a function not only of their demersal nature, but also of the brief, rapid period of gonadal recrudescence which this species undergoes prior to spawning. The rapidity with which red drum appeared to undergo vitellogenesis and gonadal growth necessitates a large and readily available energy source in the form of lipid in the liver, and suggests a dynamic endocrine regulation of cycles of nutrient deposition and mobilization.

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