# 11 Red Drum, *Sciaenops ocellatus*

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## Introduction

The red drum (*Sciaenops ocellatus*), which is also commonly called redfish or channel bass, is a euryhaline sciaenid that is native to the Gulf of Mexico and Atlantic Ocean. This fish historically supported commercial and recreational fisheries for many decades. However, commercial overfishing in the Gulf of Mexico resulted in the state of Texas prohibiting the sale of native red drum in 1981 (Matlock, 1990), and other harvest restrictions were imposed by various state and federal regulatory agencies in the early 1980s. As a result of these actions, research efforts related to the aquacultural production of this species for enhancement of wild populations as well as for food production were accelerated.

A variety of systems have been used to culture red drum. Juvenile fish are commonly raised in fertilized ponds prior to release into the wild for stock enhancement. Red drum for food markets have been reared to 1–2 kg in various culture systems, including earthen ponds, cages, net pens and raceways operating in flow-through or recirculating modes. Under favourable environmental conditions, red drum can be grown from a weight of 1 g to approximately 1 kg in 8–12 months (Sandifer *et al.*, 1993).

Nutrition of red drum is one area of research that has received considerable attention because of the influence nutrition has on fish growth and health as well as cost of production in intensive aquaculture. Nutritious and cost-effective diets have been developed to support the aquacultural production of red drum based on their established requirements for some of the most critical nutrients and energy. Dietary requirements for other nutrients continue to be investigated in addition to evaluation of diet formulations and feeding practices. This chapter will summarize information concerning nutritional requirements of the red drum, as well as discussing various aspects related to diet formulation and feeding strategies employed in its aquaculture. Nutrition and feeding of red drum during and after larval development will be considered separately, as these stages differ considerably in the fish's life history.

## Nutrition of Red-drum Larvae

Techniques for controlled spawning of red drum in captivity were developed in the 1970s and have allowed for the production of large quantities of eggs and larvae with limited effort (Arnold, 1988). Mature broodfish, typically ranging from 10 to 25 kg, are held in captivity and commonly fed combinations of shrimp, squid or fish at a rate of approximately 2.5% of body weight per day, every other day. These fish are conditioned to spawn by subjecting them to seasonal variations in temperature and photoperiod, which are commonly compressed into cycles of 120 or 150 days. The fish typically begin spawning when autumn conditions are simulated and, once spawning is initiated, environmental conditions can be adjusted slightly so that the fish continue to spawn for several months. These broodfish typically produce several hundred thousand eggs that measure less than 1 mm in diameter. The buoyant eggs, which in nature are carried by surface currents into brackish estuarine nurseries, are commonly removed from the brood tank and concentrated with the aid of a skimming device at the water's surface. The eggs hatch approximately 24 h after being spawned, and larvae derive nourishment from their yolk-sac for at least another 48–72 h. After they begin exogenous feeding, the larvae primarily consume zooplankton, such as rotifers and copepods, until reaching a size of approximately 50 mm in length (Holt, 1990).

Under aquacultural conditions, the type of zooplankton provided will depend on the larval-rearing system employed. If larval red drum are to be reared under controlled conditions in tanks, the marine rotifer (*Brachionus plicatilis*) is a preferred first food (Wohlschlag *et al.*, 1990). Stock monocultures of unicellular algae, such as *Tetraselmis chuii* or *Isochrysis* sp., are typically used to support the growth of rotifers (Treece and Wohlschlag, 1990a). Algae and rotifers have been successfully propagated separately in continuous culture as well as together in batch culture. Rotifers have also been grown with yeast and fish-oil emulsion with or without algae (Wohlschlag *et al.*, 1990). Typically, rotifers are provided for larval red drum cultured in tanks at a density of 3–5 organisms $ml^{-1}$ to ensure an adequate number of prey (Holt *et al.*, 1981). This density of rotifers is generally maintained for 7–10 days, after which the larval red drum should be large enough to consume newly hatched brine shrimp (*Artemia* sp.) nauplii, which are provided at a density of 0.5–2 organisms $ml^{-1}$ (Treece and Wohlschlag, 1990b). Procedures involved in hatching *Artemia* cysts and preparing the nauplii for feeding to larval fish are well established (Sorgeloos and Personne, 1975). Enriching rotifers and *Artemia* nauplii with highly unsaturated fatty acids (HUFA) by culturing them with fish-oil emulsion has proved beneficial in the rearing of red-drum larvae (Craig *et al.*, 1994). During the time in which larvae are fed rotifers and *Artemia* nauplii, inert microparticulate diets may also be provided.

However, commercial larval diets have not generally been able to completely replace live food organisms for larval red drum cultured intensively.

As red-drum larvae make the transition to juveniles, they may be gradually converted to an artificial dry diet. After 10–14 days of being fed *Artemia*, a high-protein starter crumble for salmonids is typically introduced to the fish, and they can normally be weaned to the artificial diet in 3–4 days. *Artemia* should continue to be fed until all fish are consuming the artificial diet. Cannibalism may be a problem in rearing red drum in intensive tank culture and can be minimized by maintaining a uniform size distribution.

Another way of providing zooplankton for larval red drum is to stock the fish in fertilized, brackish-water ponds when the water temperature is approximately 22°C or higher. This approach generally requires less labour and is commonly employed at facilities that produce juvenile fish for stock enhancement as well as at commercial production facilities. There are various organic and inorganic fertilizers that have been used to promote the growth of phytoplankton and zooplankton in larval-rearing ponds. Inorganic nutrients may include nitrogen in the form of urea and phosphorus as phosphoric acid. One of the most common organic fertilizers used in ponds for red-drum larvae is cottonseed meal. A variety of fertilization regimes, which are initiated approximately 3 weeks before stocking larvae, have been successfully used in growing the fish to juvenile size in ponds (Porter and Maciorowski, 1984). The preferred zooplankton for larval red drum in brackish-water ponds includes rotifers and copepods. Approximately 2 weeks after stocking the larval red drum, a high-protein, finely ground starter diet is typically distributed in the pond so that the fish will gradually become accustomed to eating a prepared diet. Any uneaten diet also may serve as organic fertilizer. Under good environmental conditions, red-drum larvae may grow to 37.5 mm in 30 days (Holt, 1990).

## Nutrient Requirements of Red-drum Juveniles

In nature, juvenile red drum of 60–100 mm consume small benthic invertebrates along with fish. Shrimp, crabs and fish constitute the major food items for red drum larger than 100 mm, and they consume more fish relative to crustaceans as they grow (Bass and Avault, 1975). Under aquacultural conditions, red drum readily consume artificial diets. Studies to determine the red drum's requirements for specific nutrients were initiated in the early 1980s (Robinson, 1988) and continue to date. The following sections present specific information concerning the dietary requirements of red drum for various nutrients and energy.

### *Protein and amino acids*

The minimum dietary requirement of red drum for protein consisting of a balanced mixture of amino acids has been addressed in several studies because satisfying this requirement is necessary to ensure adequate growth and health of the fish, while providing excessive levels of this most expensive component is generally uneconomic. Most of these studies have been conducted with young, rapidly growing fish to determine their minimum dietary protein requirement for maximum weight gain. Requirement values have generally ranged from 35 to 45% of diet (Daniels and Robinson, 1986; Serrano *et al.*, 1992). Most recently, the metabolic protein requirements of red drum for maintenance and maximum growth were established at approximately 2 and 20 g digestible protein (DP) $kg^{-1}$ body weight $day^{-1}$, respectively (McGoogan and Gatlin, 1998). Dietary protein requirements may vary due to a number of factors, including fish size, water temperature, protein quality, feed allowance and non-protein energy (NRC, 1993).

In addition to supplying amino acids for protein synthesis, dietary protein may also be catabolized for energy. Carnivorous fish species, in particular, appear to be very proficient at using dietary protein for energy due to the efficient way in which ammonia from deaminated protein is excreted via the gills with limited energy expenditure (NRC, 1993). A digestible energy (DE) level of approximately 15 kJ $g^{-1}$ diet (or 35–45 kJ DE $g^{-1}$ protein) has been determined to be adequate for maximum weight gain and desirable body composition of red drum (Daniels and Robinson, 1986; Serrano *et al.*, 1992). Digestible energy requirements of red drum for maintenance and maximum growth were determined to be approximately 90 and 900 kJ DE $kg^{-1}$ body weight $day^{-1}$, respectively (McGoogan and Gatlin, 1998).

Dietary requirements of red drum for some of the indispensable amino acids have also been determined. Development of a suitable test diet to quantify amino acid requirements of red drum was required because diets composed of purified ingredients, such as casein and gelatin, were not readily accepted by this species (Moon and Gatlin, 1989). Diets consisting of a limited quantity of fish-muscle protein together with crystalline amino acids to simulate the amino acid pattern of red-drum muscle protein have readily allowed quantification of this species' amino acid requirements. An alternative but less successful approach with red drum has been the use of diets containing intact unbalanced proteins supplemented with crystalline amino acids (Brown *et al.*, 1988; Craig and Gatlin, 1992).

Requirements for total sulphur amino acids (methionine plus cystine) and lysine are typically the most critical to quantify because the levels of these amino acids in feedstuffs are usually most limiting relative to the amounts required by fish. The total sulphur amino acid requirement of red drum was determined to be 3.0% of dietary protein (Moon and Gatlin, 1991). This sulphur amino acid requirement appeared to be more limiting than the lysine requirement, which was quantified to be approximately 4.4% of dietary protein (Brown *et al.*, 1988; Craig and Gatlin, 1992). The threonine requirement of red drum has also been quantified, at 2.3% of dietary protein (Boren and Gatlin, 1995). Established relationships between patterns of indispensable amino acids in muscle tissue and levels required in the diet may allow other amino acid requirements of red drum to be estimated after quantifying the requirement for only one or two of the most limiting amino acids (Wilson and Poe, 1985; Moon and Gatlin, 1991).

## *Lipids and fatty acids*

The red drum, like most other carnivorous species, has been shown to efficiently utilize dietary lipid for energy (Williams and Robinson, 1988; Ellis and Reigh, 1991; Serrano *et al.*, 1992). A total of 7 and 11% menhaden oil in diets containing 40% crude protein have produced maximum weight gain of red drum. Lipid included as high as 28% of diet did not enhance growth of red drum relative to diets containing lower levels but did increase lipid deposition in the body (McGoogan and Gatlin, 1999). Marine oils containing HUFA of the linolenic acid (n-3) family are needed to satisfy the essential fatty acid requirements of red drum (Lochmann and Gatlin, 1993a). Juvenile red drum were determined to require eicosapentaenoic acid (20:5n-3) and docosahexaenoic acid (22:6n-3) at approximately 10% of dietary lipid (Lochmann and Gatlin, 1993a,b). The red drum also appeared to have a very limited ability to elongate and desaturate shorter-chain fatty acids (Lochmann and Gatlin, 1993a).

## *Carbohydrates*

Fish do not have a specific dietary requirement for carbohydrates, but the presence of these compounds in diets may provide a rather inexpensive source of energy. However, the ability of fish to utilize dietary carbohydrate for energy varies considerably, with most carnivorous species having the most limited ability (NRC, 1993). Although the red drum is a carnivorous fish in nature, it has not generally been shown to be adversely affected by high levels of soluble carbohydrate in the diet, although lipid is used preferentially to carbohydrate. In two different studies, red drum generally had better weight gain and feed efficiency when fed diets containing more lipid and less carbohydrate relative to other diets estimated to be isoenergetic (Ellis and Reigh, 1991; Serrano *et al.*, 1992). Results from other studies have indicated that red drum was not adversely affected by as much as 35% soluble carbohydrate in the diet, although in some instances weight gain and feed efficiency were slightly reduced (Daniels and Robinson, 1986; Davis and Robinson, 1987; Williams and Robinson, 1988).

Fibrous carbohydrates, such as cellulose and hemicellulose, are essentially indigestible by fish and thus do not make a positive contribution to their nutrition. Typically, the level of crude fibre in red-drum diets is restricted to less than 7% to limit the amount of undigested material entering the culture system.

## *Vitamins and minerals*

There are 15 vitamins established as being essential for terrestrial animals as well as for many of the fish species that have been extensively studied (NRC, 1993). Currently there is specific information on the quantitative dietary requirements of red drum for only choline (Craig and Gatlin, 1996) and ascorbic acid (Aguirre and Gatlin, 1999). Typically, a vitamin premix based on vitamin requirements of other fish species is added to commercial diets for red drum to provide adequate levels of each vitamin independent of levels in ingredients. This supplement will also provide a margin of safety for losses associated with diet processing and storage.

It has been established with several fish species that they require the same minerals as terrestrial animals for tissue formation and other metabolic functions, including osmoregulation (NRC, 1993). However, some water-borne minerals may contribute to satisfying the metabolic requirements of fish and interact with dietary requirements.

Of the macrominerals, phosphorus has received considerable attention because its presence in water and utilization by fish are generally limited. The total phosphorus requirement of red drum has been determined to be 0.86% of diet (Davis and Robinson, 1987). However, the availability of phosphorus from feedstuffs may vary considerably, as noted with red drum (Gaylord and Gatlin, 1996); thus, supplementing diets on the basis of available phosphorus is important. In addition to phosphorus supplementation, inclusion of 2% sodium chloride and/or 2% potassium chloride in practical diets has been shown to have positive effects on growth of red drum in fresh water and brackish water (6 p.p.t.), but no such effects were observed in full-strength artificial sea water (Gatlin *et al.*, 1992). The beneficial effects of adding a supplement of salt to diets for red drum in fresh water and brackish water appeared to be due to a metabolic need for these ions in hypotonic environments. Dietary requirements of red drum for other macrominerals have not been investigated.

Of the microminerals, zinc (Zn) has been demonstrated in some fish species to be most important to supplement in diets due to its low level in practical feedstuffs and/or interactions with other dietary components that may reduce its bioavailability (NRC, 1993). At this time, only the dietary zinc requirement of red drum has been determined (Gatlin *et al.*, 1991). A minimum requirement of 20–25 mg Zn $kg^{-1}$ diet was quantified using semipurified diets, although higher levels are generally supplemented. Other micromineral requirements have not been determined for red drum at this time. However, an inexpensive trace-mineral premix is typically added to most nutritionally complete diets to ensure adequacy (NRC, 1993).

## Practical Diets

Costs associated with diets and feeding generally constitute the largest variable expense in intensive production of red drum, as with other fish species; therefore, formulation of cost-effective diets can significantly influence the profitability of the aquacultural enterprise. In addition, red drum under intensive production schemes must derive essentially all nutrients from prepared diets; therefore, proper nutrition is critical to maintaining efficient growth and optimal health of the fish.

The accuracy of diet formulation can be improved if information about the digestibility or availability of various nutrients from feedstuffs is known. Such information has been obtained for red drum for most of the commonly used feedstuffs (Gaylord and Gatlin, 1996; McGoogan and Reigh, 1996). Feedstuffs of marine origin, including various fish-meals, have been most effective in diet formulations for carnivorous species such as red drum because they are generally quite palatable and high in protein, lipid and DE. However, these feedstuffs are usually quite expensive and may substantially increase the cost of diet formulations. Other feedstuffs from animal by-products have been used to replace fish-meal with some success (Moon and Gatlin, 1994; Meilahn *et al.*, 1996); however, their quality can be variable. Several protein feedstuffs of plant origin, such as soybean meal and cottonseed meal, are less expensive but have had limited use in diet formulations because they may be deficient in at least one indispensable amino acid and are usually less palatable to carnivorous species (Reigh and Ellis, 1992; Davis *et al.*, 1995). However, in one study, relatively high dietary levels of soybean meal could be included without reducing growth or feed intake of red drum if a minimum of 10% of dietary protein was provided by fish-meal (McGoogan and Gatlin, 1997).

A variety of by-products from grains such as maize and wheat have been used in fish diets to supply available carbohydrate for energy and improve pellet stability. Relatively high levels of these feedstuffs can be included in red-drum diets that are manufactured by extrusion processing, because this species is not adversely affected by soluble carbohydrate (Ellis and Reigh, 1991; Serrano *et al.*, 1992).

Lipids of marine origin are commonly included in diets of red drum to provide essential fatty acids and improve palatability. Marine lipids containing high levels of n-3 HUFA have also been shown to confer increased tolerance of red drum to cold water temperatures due to incorporation of these fatty acids into membrane lipids (Craig *et al.*, 1995). Alternative lipid sources, including saturated and relatively unsaturated animal and vegetable lipids, have also been shown to be well utilized by red drum, as long as the fish's requirement for n-3 HUFA is met (Craig and Gatlin, 1995; Tucker *et al.*, 1997). Due to this species' tendency to deposit large amounts of lipid in the liver and visceral cavity, alternative lipids, such as medium-chain triglycerides, have also been investigated (Craig and Gatlin, 1995; Davis *et al.*, 1999). These compounds generally reduce lipid deposition but do not support rapid fish growth. Another type of dietary lipid that has been shown to enhance the growth of very young red drum is phospholipid in the form of soybean lecithin (Craig and Gatlin, 1997). However, it is not likely that the cost of phospholipid addition to diets composed of practical feedstuffs is warranted once the fish are larger than 50 g. Commercially available vitamin and mineral premixes are also commonly included in diets for red drum, although more specific information about requirements for these nutrients is needed.

A variety of production diets have been evaluated with red drum in controlled feeding trials (McGoogan and Gatlin, 1997; Thoman *et al.*, 1999). Results of these studies generally indicate that a crude protein level of 40% or greater is needed to support the most rapid growth of red drum. Providing the proper amount of dietary energy relative to protein (and other nutrients) is also critical for ensuring adequate nutrient intake, since the fish's intake may be regulated by energy (NRC, 1993). However, a recent study with red drum indicated that diet intake was more directly influenced by body size than by dietary energy density (Thoman *et al.*, 1999). A balanced dietary energy-to-protein ratio is also important in order to maximize use of dietary protein for protein synthesis rather than for catabolism for energy. Optimizing the dietary energy-to-protein ratio was able to reduce ammonia excretion of red drum (McGoogan and Gatlin, 1999, 2000).

Table 11.1 shows a practical diet formulation that meets all known requirements of red drum. Research to determine the cost-effectiveness of different diet formulations for red drum has been rather limited to date but deserves further consideration.

Juvenile red drum are typically fed crumbled pellets until they reach a size at which extruded pellets can be readily consumed. Production diets are often produced by extrusion processing because the resulting pellets have high water stability and low density, which may allow them to float. This characteristic assists the aquaculturist in monitoring the fish's intake, especially in large culture systems. A general guide relating diet particle size to the size of red drum is presented in Table 11.2.

**Table 11.1.** A model diet formulation containing 40% crude protein and 15.1 kJ digestible energy $g^{-1}$ for growing red drum from juvenile to adult size (from Gaylord and Gatlin, 1996).

| Ingredient | g $kg^{-1}$ as fed |
|---|---|
| Menhaden fish-meal | 32.3 |
| Soybean meal (48% protein) | 26.0 |
| Meat and bone-meal | 10.0 |
| Wheat grain | 26.0 |
| Menhaden fish-oil | 5.0 |
| Mineral premix* | 0.1 |
| Vitamin premix* | 0.1 |
| Dicalcium phosphate | 0.5 |

* Similar to those used for other warm-water fish species.

**Table 11.2.** Suggested diet particle sizes for red drum of various sizes.

| Fish weight (g) | Diet particle size (mm) |
|---|---|
| 0.25–0.5 | 0.25 |
| 0.6–1.0 | 0.50 |
| 1.1–2.0 | 1.5 |
| 2.25–4.0 | 2.0 |
| 5.0–20 | 2.5 |
| 25–50 | 3.0 |
| 55–150 | 3.9 |
| 175–300 | 4.7 |
| 325–500 | 6.25 |
| > 500 | 9.4 |

## Feeding Practices

Appropriate feeding schedules and practices must be employed in the aquacultural production of red drum, as with other species, to ensure that maximum benefit can be derived from prepared diets. It is generally desirable to provide red drum with as much diet as they will consume on a regular basis. However, excessive feeding should normally be avoided because it not only wastes expensive diet but may also cause the water quality to deteriorate.

Feeding schedules for red drum, like other species, are influenced by fish size and water temperature. In general, smaller fish consume more feed when expressed as a percentage of body weight than do larger fish. Red drum weighing less than 5 g typically consume prepared diets at over 7% of body weight $day^{-1}$. In contrast, 50 g red drum consumed diet at approximately 5% of body weight $day^{-1}$ and fish over 250 g consumed less than 2% of body weight $day^{-1}$ (Thoman *et al.*, 1999). Smaller fish should also be fed more frequently than larger fish due to their higher metabolic rates. In addition, water temperature may also significantly influence feed intake, with reduced consumption occurring above and below the optimal temperature range. Specific feeding schedules for red drum have been empirically derived. The means by which diet is administered to red drum is largely dictated by the design and size of the culture systems.

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