# Carbon Footprint of US Farm-Reared Catfish

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## Abstract

*The carbon footprint for aquacultured channel catfish was determined by measuring fuel use and then estimating the associated carbon emissions for construction of ponds, production and transport of feed ingredients to feed mills, feed manufacturing and delivery, production and delivery of fingerlings, farm operations, harvesting, processing, offal management, and transportation of final product to major distribution centers. The total carbon emissions were 3.63 lb $CO_2$/lb live fish, but ponds used for production sequestered carbon in sediment. Adjusting for carbon sequestration, net carbon emissions – carbon footprint of catfish – was 2.77 lb $CO_2$/lb live fish or 5.48 lb $CO_2$/lb final product delivered to a major distribution center.*

*The carbon emissions associated with individual tasks were: pond construction, 1.00%; fingerlings, 0.60%; feed ingredients and delivery, 55.16%; feed manufacturing and delivery, 5.58%; farm-level activities, 25.02%; processing and waste, 7.61%; product transportation, 5.05%. Like most meat products, more than half of the carbon footprint of catfish resulted from feed ingredients.*

*Catfish have a lower carbon footprint than pork or beef, but possibly a slightly greater carbon footprint than chicken. There are too few data for making a fair comparison of catfish to other aquacultured species – although catfish appear to compare favorably with aquacultured salmon. Wild-caught fisheries products tend to have a lower carbon footprint than aquacultured species.*

## Introduction

The atmospheric $CO_2$ concentration has increased from an estimated 280 ppm at the beginning of the industrial age in the mid 1800s (Gitay et al. 2002) to about 390 ppm today (http://co2unting.com/index.html). This rise in $CO_2$ concentration in the atmosphere is thought by most climatologists to be causing the average world temperature to increase (Solomon et al. 2007). There is a global effort to control $CO_2$ emissions that includes an attempt to reduce global $CO_2$ emissions by encouraging consumers to preferentially purchasing products with a low carbon "footprint." A carbon "footprint" is the net amount of carbon dioxide ($CO_2$) emitted to the atmosphere as a direct or indirect result of producing a particular good or service (Wiedmann and Minx 2007). Wholesalers and retailers increasingly request information on the carbon footprint of products.

The carbon footprint usually is determined by estimating quantities of all fuel used in supplying a good or service, and applying standard factors for estimating $CO_2$ emissions from the amount of fuel used. The purpose of this study was to determine $CO_2$ emissions associated with production of feed ingredients, transportation of these ingredients, feed manufacturing, pond construction, farm activities, processing, and initial distribution of processed product for aquacultured channel catfish in the United States. The sum of these emissions was taken as the carbon footprint of channel catfish production.

## Methods

Fuel use data were obtained from several sources as follows: one large hatchery, two large catfish feed mills, one pond construction contractor, 12 Alabama catfish farms, a database for fuel use on 67 catfish farms in Mississippi, an evaluation of fuel use on different sizes of catfish farms in Arkansas (Engel 2007), one custom harvesting crew, and five processing plants. Additional information on survival of fingerlings in ponds, fuel to transport feed ingredients, fingerlings, and salt and gasoline used on Alabama farms were based on discussions with various individuals knowledgeable about each topic. Data on feed use and channel catfish production were obtained from USDA statistics (NASS 2010). Data on energy use for producing feed ingredients were obtained from Pelletier et al. (2009, 2010a,b). Fuel use data were converted to $CO_2$ emissions using standard factors (Table 1). The $CO_2$ emissions were estimated in terms of pounds of $CO_2$ emitted per pound of live fish processed.

Table 1. Carbon dioxide emissions equivalents for use of different types of fuel.

| Fuel | Carbon dioxide |
|---|---|
| Gasoline, regular | 19.564 lb/gal[1] |
| Diesel, No. 2 | 22.384 lb/gal[1] |
| Natural gas | 117.08 lb/mm BTU[1] |
| Propane | 5.761 lb/gal[1] |
| Electricity | 1.470 lb/kW·h[2] |

[1]Voluntary reporting of greenhouse gases program, fuel and energy source codes and emission coefficients. (http://www.eia.doe.gov/oiaf/1605/coefficients.html)
[2]Carbon dioxide emissions from the generation of electric power in the United States. (http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2emiss.pdf).

## Calculations

### Pond construction

An average of 160 gal/ac of diesel fuel was used for pond construction. Ponds can be operated for catfish culture for about 20 yr before major renovation is necessary (Boyd et al. 2000); fuel use amortized over 20 yr is 8 gal/ac/yr. Sales of food-size catfish in 2010 amounted to 471,682,000 lb from 95,200 ac (NASS 2010) – 4,955 lb/ac.

$$\mathrm{CO_2} = \frac{(\text{ 8 gal DF/ac})(22.384 \text{ lb } \mathrm{CO_2}\text{/gal})}{4{,}955 \text{ lb/ac live fish}} = 0.0361 \text{ lb } \mathrm{CO_2}\text{/lb live fish}$$

### Hatchery operations

The hatchery used 180,291 kW·h electricity and 833 gal diesel fuel to produce 12,000,000 fingerlings. The average harvest weight of food fish is about 1.9 lb (NASS 2010). Assuming a fingerling survival rate of 70% from stocking to harvest in grow-out ponds, fingerlings from the hatchery should have resulted in 8,400,000 fish weighing a total of 15,960,000 lb.

$$\mathrm{CO_2} = \frac{(180{,}291 \text{ kW} \cdot \text{h } \times 1.47) + (833 \text{ gal } \times 22.384)}{15{,}960{,}000 \text{ lb live fish}} = 0.0178 \text{ lb } \mathrm{CO_2}\text{/lb live fish}$$

### Fingerling delivery

Catfish production of 471,682,000 lb represents about 354,648,120 fingerlings (1.9 lb harvest weight; 70% survival). Fingerling transport trucks haul about 210,000 fingerlings per trip, thus, about 1,689 trips were required to deliver the fingerlings. We believe that about 30% of fingerlings were transported from Mississippi hatcheries to Alabama (507 trips); an estimated roundtrip distance of 500 mi. The other fingerlings were produced closer to the ponds to which they were delivered – estimated roundtrips of 150 mi each. It will be assumed that trucks had a gas mileage efficiency of 5.5 mi/g and used diesel fuel. The total mileage for transporting fingerlings was estimated at 430,800 mi, and 78,327 gal of fuel were consumed.

$$\mathrm{CO_2} = \frac{(78{,}327 \text{ gal})(22.384)}{471{,}682{,}000 \text{ lb live fish}} = 0.0037 \text{ lb } \mathrm{CO_2}\text{/lb live fish}$$

### Feed ingredients

The $CO_2$ required to produce feed ingredients was estimated by determining the ratio of each feed ingredient in the feed and multiplying this value by the ratio of $CO_2$ emitted during production to unit of feed ingredient (Table 2). The $CO_2$ emission values were 1.181 lb $CO_2$/lb feed for feed mill A and 0.734 lb $CO_2$/lb feed for feed mill B. The reason for the large difference is that feed mill A used a lot of Pro-con compared to feed mill B, and Pro-con has a very high

$CO_2$ ratio (Table 2). Feed mill A produced 249,932,000 lb feed while feed mill B produced 300,118,000 lb feed. The weighted average for feed ingredient $CO_2$ emissions is 0.9371 lb $CO_2$/lb feed. The average feed conversion ratio (FCR) (weight feed ÷ fish produced) was estimated to be 2.11 from weight feed delivered to farms for food-size fish and quantity of fish processed (NASS 2011). Thus, the $CO_2$ emissions for feed ingredients were 1.9598 lb $CO_2$/lb live fish.

Table 2. Carbon dioxide ($CO_2$) ratios for producing feed ingredients, ratios of ingredients in feed, and $CO_2$ emissions for production of each ingredient included in channel catfish feed.

| Feed ingredient | Ingredient $CO_2$ ratio (lb/lb feed) | Feed mill A | | Feed mill B | |
|---|---|---|---|---|---|
| | | Feed ratio (lb/lb feed) | $CO_2$ (lb/lb feed) | Feed ratio (lb/lb feed) | $CO_2$ (lb/lb feed) |
| Soybean meal | 0.369 | 0.336 | 0.124 | 0.358 | 0.132 |
| Pro-con | 5.86 | 0.108 | 0.634 | 0.013 | 0.077 |
| Corn | 1.122 | 0.203 | 0.228 | 0.093 | 0.105 |
| Cottonseed meal | 0.500 | 0.096 | 0.048 | 0.061 | 0.031 |
| Wheat middlings | 0.453 | 0.242 | 0.110 | 0.247 | 0.112 |
| Fish oil | 2.792 | 0.013 | 0.036 | 0.011 | 0.032 |
| Mineral mix | 1.00 | 0.001 | 0.001 | 0.001 | 0.001 |
| Vitamin mix | 1.00 | 0.001 | 0.001 | 0.001 | 0.001 |
| Corn gluten | 1.122 | | | 0.201 | 0.226 |
| Fish meal | 2.002 | | | 0.005 | 0.010 |
| Other | 1.000 | | | 0.008 | 0.008 |
| Total | | | 1.181 | | 0.734 |

## Feed ingredient transport

All ingredients were transported to feed mill A by truck. Barge, rail, and truck transport was used to deliver ingredients to feed mill B. Cities of origin of the ingredients, roundtrip transport distances for trucks and one-way distances for barge and rail were determined. Fuel efficiency of 5.5 mi/gal and 25-ton load was assumed for trucks. Barge transport was assumed to consume 0.00083 gal DF/ton/mi (Maritime Administration 1994); rail transport was assumed to use 0.0021 gal DF/ton/mi (Association of American Railroads 2011). To avoid identifying the feed mills, the calculations of fuel use will not be given, but 470,185 gal of diesel fuel were used to transport 265,945 ton of ingredients from sources of origin to feed mills.

$$CO_2 = \frac{(470{,}185 \text{ gal})(22.384)}{545{,}050{,}000 \text{ lb feed}} = 0.0193 \text{ lb } CO_2/\text{lb feed}$$

At a FCR of 2.11, the emissions per lb fish are:

$$0.0193 \text{ lb } CO_2/\text{lb feed} \times 2.11 = 0.0407 \text{ lb } CO_2/\text{lb live fish.}$$

## Feed manufacturing

Feed mill A used 5,263,554 kW·h electricity and 96,300 million BTU of natural gas to produce 244,932,000 lb feed, while feed mill B manufactured 300,118,000 lb feed using

10,839,000 kW·h electricity and 21,953 million BTU of natural gas. Thus, 16,102,554 kW·h electricity and 118,253 million BTU of natural gas were used to manufacture 545,050,000 lb of catfish grow-out feed. Assuming a FCR of 2.11, 258,317,536 lb of fish were produced with the feed. The resulting $CO_2$ emissions were:

$$\mathrm{CO_2} = \frac{16{,}102{,}554 \text{ kW·h } \times 1.47) + (118{,}253 \text{ m BTU NG})(117.08)}{258{,}317{,}536 \text{ lb live fish}}$$

$$= 0.1452 \text{ lb } \mathrm{CO_2}/\text{lb live fish.}$$

Feed delivery and miscellaneous vehicle use

The two feed mills used a total of 99,437 gal diesel fuel and 2,339 gal gasoline to deliver feed to farms and for miscellaneous purposes.

$$\mathrm{CO_2} = \frac{(99{,}437 \text{ gal } \times 22.384) + (2{,}339 \text{ gal } \times 19.564)}{258{,}317{,}536 \text{ lb fish produced with feed}} = 0.0088 \text{ lb } \mathrm{CO_2}/\text{lb live fish}$$

Fingerling feed manufacturing

Data were not available for fuel use to produce fingerling feed. Thus, it was assumed that fuel use for fingerling feed was the same as for grow-out feed. Fingerlings are typically grown to 4- to 6-inch (average of 37 lb/thousand) before stocking in grow-out ponds, and an FCR of 1.7 is typical in fingerling ponds. For 70% survival of fingerlings from stocking to food-size fish, one thousand fingerlings at stocking equates to 700 food-size fish weighing a total of 1,330 lb at harvest. The $CO_2$ emissions attributable to production of 1 lb of food-size fish can be estimated from ratios of fingerling FCR:food fish FCR and weight of 1,000 fingerling:weight of 700 food fish. The $CO_2$ emissions associated with producing grow-out feed totaled 2.1545 lb $CO_2$/lb live fish (from Table 3), and $CO_2$ emissions related to fingerling feed were:

$$\mathrm{CO_2} \text{ emissions} = 2.1545 \text{ lb } \mathrm{CO_2}/\text{lb live fish } \times \frac{1.70}{2.11} \times \frac{37}{1{,}330} = 0.0483 \text{ lb } \mathrm{CO_2}/\text{lb live fish.}$$

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Farm operations

Farms use electricity for floating aerators, diesel fuel for tractors used in emergency aeration, mowing, and feeding, and gasoline in light trucks and boats used in pond management. Twelve farms in Alabama used an average of 40.89 gal diesel fuel, 1,307 kW·h electricity, and 25 gal gasoline per acre per year, and they produced an average of 4,780 lb fish/yr. The database for fuel use in Mississippi was separated into the Delta region in the west and the Blackbelt region in the east. In the Delta, 19.6 gal gasoline, 27.36 gal diesel fuel, and 2,285 kW·h electricity/ac were used to produce 3,998 lb/ac of catfish. In the Blackbelt, 12.56 gal gasoline, 36.99 gal diesel fuel, and 2,586 kW·h electricity/ac were used to produce 5,779 lb/acre of catfish.

Data from Arkansas revealed that farms up to 256 ac in production area used 26.4 gal diesel fuel, 10.6 gal gasoline (reported as gasoline plus diesel, and it was assumed the ratio of the two fuels used was the same as in the Mississippi Delta), and 2,612 kW·h electricity/ac, and they produced 4,500 lb fish/ac. Larger farms used the same amount of gasoline and diesel fuel per acre as smaller farms. However, larger farms used the less electricity – 1,894 kW·h/ac to produce 4,500 lb fish/ac.

The average fuel use at the farm level was 31.62 gal diesel fuel, 15.67 gal gasoline, and 2,136.8kW·hr electricity/ac; production averaged 4,711 lb/ac.

Carbon emissions were:

Floating aerators:

$$CO_2 = \frac{(2136.8 \text{ kWh ac})(1.47)}{4{,}711 \text{ lb ac}} = 0.6668 \text{ lb } CO_2/\text{lb live fish.}$$

Emergency aeration, feeding, and mowing:

$$CO_2 = \frac{(31.62 \text{ gal})(22.384)}{4{,}711 \text{ lb ac}} = 0.1502 \text{ lb } CO_2/\text{lb live fish.}$$

Light truck and boat use:

$$CO_2 = \frac{(15.67 \text{ gal gasoline})(19.564)}{4{,}711 \text{ lb ac}} = 0.0651 \text{ lb } CO_2/\text{lb live fish.}$$

Salt delivery to farms

Reliable information on salt delivery to farms could be obtained only for Alabama. Crusher run salt (NaCl) is shipped by barge from the mines in Louisiana to Columbus, Mississippi (440 mi). The salt is then trucked to distribution points in the catfish farming region (average roundtrips of 220 mi). The salt is delivered to farms by tender truck (estimated roundtrips of 60 mi). Barge transport has a fuel efficiency of around 0.00083 gal diesel/ton/mi, and the trucks typically haul 25 tons with a fuel efficiency of 5.5 mi/gal (0.182 gal/mi). The average salt application is around 600 lb (0.3 ton)/yr (Bill Hemstreet, Alabama Fish Farming Center).

$$\text{Fuel use} = (440 \text{ mi} \times 0.00083 \text{ gal/ton/mi} \times 0.3 \text{ ton/ac})$$

$$+\left(\frac{0.3 \text{ ton/ac}}{25 \text{ ton/truck}} \times 260 \text{ mi} \times 0.182 \text{ gal/mi}\right) = 0.6774 \text{ gal/ac}$$

$$CO_2 = \frac{(0.6774 \text{ gal})\ (23.384)}{4{,}955 \text{ lb fish/ac}} = 0.0032 \text{ lb } CO_2/\text{lb live fish}$$

The carbon emissions for salt are small, so even if less fuel is used to deliver salt in other states, use of the value based only on Alabama data would not introduce a significant error.

Harvesting and transport to processor

The custom harvesting crew used 8,657 gal gasoline and 90,270 gal diesel fuel while harvesting and delivering 98,074,321 lb fish.

$$\mathrm{CO_2} = \frac{(8{,}657\text{ gal } \times 19.564) + (90{,}270\text{ gal } \times 22.384)}{98{,}074{,}321\text{ lb live fish}} = 0.0223\text{ lb }\mathrm{CO_2}/\text{lb live fish}$$

Processing

Data from the five processing plants were pooled. The plants processed 129,642,000 lb live fish yielding 65,528,000 lb of product (output = 50.5%). Total fuel use was 555 million BTU of natural gas, 23,037 gal of propane, and 22,908,164 kW·h electricity.

$$\mathrm{CO_2} = \frac{(555\text{ m BTU } 117.08) + (23{,}037\text{ gal } \times 5.76) + (22{,}908{,}164\text{ kW·h } \times 1.47)}{129{,}642{,}000\text{ lb live fish}}$$

$$= 0.2613\text{ lb }\mathrm{CO_2}/\text{lb live fish}$$

Delivery to major distribution points

The processing plants provided data on fuel used by their truck fleets to deliver product, and it is assumed that the product transported by other trucks would result in similar carbon emissions. The five processing plants reported hauling 45,462,000 lb product and using 703,924 gal diesel fuel – 14.2% of fuel was used to power the refrigeration units in the trailers.

$$\mathrm{CO_2} = \frac{(703{,}924\text{ gal})\ (22.384)}{(45{,}462{,}000\text{ lb product } \div 0.5055} = 0.1830\text{ lb }\mathrm{CO_2}/\text{lb live fish}$$

Offal delivery

The plants used 62,205 gal diesel fuel to transport their offal to rendering facilities.

$$\mathrm{CO_2} = \frac{(62{,}205\text{ gal})\ (22.384)}{129{,}642{,}000\text{ lb fish}} = 0.0112\text{ lb }\mathrm{CO_2}/\text{lb live fish}$$

Miscellaneous car use by processing plants

The plants used 23,445 gal of gasoline in cars and pickups used by sales force and for other purposes.

$$CO_2 = \frac{(23{,}445 \text{ gal})\ (19.564)}{129{,}642{,}000 \text{ lb fish}} = 0.035 \text{ lb } CO_2/\text{lb live fish}$$

## Discussion

The total amount of $CO_2$ emitted for the production of 1 lb of live catfish and delivery of the resulting meat to major distribution centers was estimated to be 3.63 lb (Table 3).

Table 3. Carbon dioxide ($CO_2$) emissions for various tasks in channel catfish production and total carbon emissions for producing and processing 1 lb of live fish and delivering the resulting product (edible meat) to distribution centers.

| Activity | $CO_2$ emissions (lb $CO_2$/lb live fish) |
|---|---|
| Pond construction | 0.0361 |
| Fingerlings: | |
| Production | 0.0178 |
| Delivery | 0.0037 |
| Feed: | |
| Ingredient production | 1.9598 |
| Ingredient transport | 0.0407 |
| Manufacturing | 0.1452 |
| Delivery | 0.0088 |
| Fingerling feed | 0.0483 |
| Farm operations | |
| Paddlewheel aerators | 0.6668 |
| Tractor use – emergency aeration, feeding, mowing | 0.1502 |
| Light truck and boat use | 0.0651 |
| Salt delivery to farms | 0.0032 |
| Harvesting | 0.0223 |
| Processing: | |
| Processing plant (slaughter and dress-out) | 0.2613 |
| Product delivery | 0.1830 |
| Offal delivery | 0.0112 |
| Miscellaneous car use | 0.0035 |
| Total | 3.6269 |

The distribution of the emissions among task categories were:

- Pond construction, 1.00%
- Fingerlings, 0.60%
- Feed ingredients and delivery, 55.16%
- Feed manufacturing and delivery, 5.58%
- Farm-level activities, 25.02%

- Processing and waste, 7.61%
- Product transportation, 5.05%

It is interesting to note that 55.16% of the $CO_2$ was emitted in producing and transporting the feed ingredients. The catfish industry has no control over carbon emissions resulting from the production of feed ingredients.

Catfish ponds sequester carbon in sediment at a rate of 5,768 lb $CO_2$/ac/yr (Steeby et al. 2004; Boyd et al. 2010). This amounts to 0.8590 lb $CO_2$/lb live fish. Subtraction of carbon dioxide sequestered by the ponds from carbon emissions calculated in this study (Table 3) gives a net carbon emissions value of 2.77 lb $CO_2$/lb live fish.

The net carbon emissions for processed product – assuming an output of 50.55% by processing plants – are 5.48 lb $CO_2$/lb product. This value is considerably greater than the carbon emissions estimated last year for Alabama catfish only. However, the earlier carbon footprint estimation did not include the carbon emissions associated with the production of feed ingredients – 54% of total emissions.

We devoted considerable effort to finding information on the carbon footprints of other meat products including aquacultured and wild-caught fish and shrimp. A fairly large number of estimates were found, but in most cases, it was not clear as to the production tasks for which emissions were included in the carbon footprint. There are several references that give values of around 12 to 16 lb $CO_2$/lb beef, 4 to 8 lb $CO_2$/lb pork, and 3 to 4 lb $CO_2$/lb chicken. However, one reference provided good information on which emissions were included in the carbon footprint for pork. The carbon footprint for pork was reported as 2.2 lb for a 4 oz serving (http://nationalhogfarmer.com/environmental-stewardship/regulations/layers-of-porks-carbon-footprint). The breakdown of emissions by task follows:

- 13.6% - breeding and lactating sows, including feed and manure handling
- 53% - nursery to finish, including feed and manure handling
- 6.7% - processing and packaging
- 14% - retail handling
- 13% - consumer use.

The catfish carbon footprint does not include retail handling and consumer use. If we assume that half the emissions for retail handling of pork was the result of transportation to major distribution points, then 80% of the tasks used in the pork carbon footprint were equivalent to the ones used in the catfish carbon footprint. The adjusted pork carbon footprint (up to major distribution points) is:

$$2.2 \text{ lb } \mathrm{CO_2}/4 \text{ oz pork} \times \frac{16 \text{ oz/lb}}{4 \text{ oz}} \times 0.8 = 7.04 \text{ lb } \mathrm{CO_2}/\text{lb}.$$

The corresponding value for catfish is 5.48 lb $CO_2$/lb product – lower than for pork.

Although some references indicate a lower carbon footprint for chicken, many give a similar value for pork and chicken. We suspect that the chicken carbon footprints that we found were for farm-level product rather than processed product. It is possible though that the short grow-out period and the improvements in ability of chickens to convert feed (resulting from genetic improvement) lead to a much lower carbon footprint. However, we could not resolve this issue. But, beef clearly has a much greater carbon footprint than pork, chicken, or catfish.

The most reliable data on carbon footprints of aquaculture products versus those of wild-caught fisheries products were provided by Winther et al. (2009). The data included fuel used in the fishery, processing, and transport to major centers for wild-caught products and fuel for feed ingredients and feed products, culture, processing, and transport for aquaculture products. Wild-caught species were cod, saithe, haddock, herring, and mackerel; aquaculture species were salmon and blue crab. Carbon footprints ranged from 0.98 to 3.84 lb $CO_2$/lb product (average = 2.47 lb $CO_2$/lb product) for wild-caught fish. The lower carbon footprint of wild-caught aquaculture products is not surprising, because no feed was used to produce wild-caught animals. Carbon footprints for aquacultured salmon averaged 5.26 kg $CO_2$/kg product (range = 2.47 to 13.86 kg $CO_2$/kg product). The carbon footprint of aquacultured blue crab was 2.54 kg $CO_2$/lb product.

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