

**Sexual Development of Common Dolphinfish,
Coryphaena hippurus, and Fisheries Management Implications**

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Abstract

Common dolphinfish, *Coryphaena hippurus*, are an abundant, highly prized pelagic game and commercial fish, and despite their importance, information on the dolphinfish mating system is lacking. Dolphinfish are unique among pelagic fishes due to their striking sexual dimorphism, and the function of this dimorphism is currently unknown although it may reflect a very different social structure compared to monomorphic species such as tunas. A total of 58 samples, 23 females and 35 males, caught by recreational fishermen in the Southern California Bight were examined for sexual dimorphism and sexual development. Measurements of the dorsal-fin height, the linear length of the forehead, and the contour length of the forehead were performed and histological sections of the gonads were examined to determine reproductive status and to confirm sex. The morphological measurements show that the majority of males of any given size have larger head and fin features than the females. Among males, sexual dimorphism was not correlated with sexual maturity: males less than approximately 60 cm fork length, resembled females in forehead shape and dorsal-fin height, but were sexually mature. If dolphinfish exhibit a more complex mating system with large males behaving as territorial bulls and monopolizing groups of females, then fisheries managers should consider this potential social structure when developing population dynamics models and management strategies because reproduction may be affected by intense exploitation.

Introduction

There is a grave concern among the scientific community that fisheries exploitation has severely depleted the populations of large predatory fishes (Worm et al. 2005; Myers et

al. 2003). While dolphinfish, *Coryphaena hippurus*, are currently not considered overexploited, fishing pressure on them is increasing. Accurate life history information is needed to develop reliable population dynamics models for large pelagic fishes, and thereby aid fishery managers in developing appropriate management plans.

Dolphinfish are highly prized game and commercial fish throughout their range (Oxenford 1999), and they are also taken as bycatch in the tuna purse seine fishery (<http://www.dfg.ca.gov/MRD/status/dolphin.pdf> March 2007). Recreational fisheries, in particular, are economically valuable in the United States and Mexico, and dolphinfish are an important component of the catch in the Commercial Passenger Fishing Vessel (CPFV) fleet.

Locally, the CPFV fleet departs from sportfish landings, marinas, and launch ramps from Los Angeles to San Diego (PFMC 2003). The fleet consists of approximately 200 vessels and each vessel carries up to 30 passengers per trip. Approximately 1 million passengers fish local and Mexican waters annually on the CPFV fleet contributing about \$80 million to the economy of California (Hewitt 2005).

The recreational catch of dolphinfish has increased in the past 30 years, and particularly in the last decade (Norton 1999). According to the California Department of Fish & Game, the annual dolphinfish catches for the CPFV prior to 1972 were less than a few hundred fish whereas after 1972 the catches were greater than 1,000 fish during the July through October fishing season (<http://www.dfg.ca.gov/MRD/status/dolphin.pdf> March

2007). Dolphinfinch were also one of the top 5 species captured in the CPFV fleet for the past five years following albacore, yellowfin tuna, bluefin tuna, and skipjack (<http://www.pcouncil.org> March 2007). From 1994-2004 dolphinfinch were the second most frequently taken fish following albacore by private recreational vessels (<http://www.pcouncil.org> March 2007).

Currently, the Western Pacific Fisheries Management Council (WPFMC), National Marine Fisheries Service (NMFS), has no stock assessment for dolphinfinch in the eastern North Pacific. The stock status is unknown, and no specific management measures for dolphinfinch are in effect (WPFMC 2005). Consequently, it is time to adopt a precautionary approach to management of dolphinfinch fisheries and to do this, it is essential to understand the biology of the species. At present there is a lack of information regarding movements and life history patterns (Dewar pers. comm.) in the Southern California Bight.

Life History

Dolphinfinch are epipelagic and are found in tropical, subtropical, and temperate oceans of the world (Palko et al. 1982). Temperature appears to control the distribution of dolphinfinch because they are limited by the 20°C isotherm (Gibbs and Collette 1959). Therefore, dolphinfinch extend their habitat northward during the warmer water months, typically July through October. Norton (1999) suggested that their habitat is expected to increase if ocean temperatures continue to warm.

Dolphinfish are fast growing fish with a maximum lifespan of approximately four years, although the average longevity is less than two years (Oxenford 1999). They are multiple spawners and spawn throughout the year in tropical waters (Palko et al. 1982).

Dolphinfish are highly fecund, with 80,000-1,000,000 eggs released per spawning event (Beardsley et al. 1967). Size at first maturity differs by location, size, and age, with females maturing at a slightly smaller size than males but similar age (Oxenford 1999).

Dolphinfish are unique among pelagic fishes due to their striking sexual dimorphism.

The function of this dimorphism is unknown, although schooling occurs by sex and size and they typically associate with floating objects (NMFS 2001), which increases their vulnerability to fishing (Palko et al. 1982). Males possess a prominent bony crest that easily distinguishes them from females. Understanding the function of this dimorphism is important for conservation and fisheries management because it may reflect a very different social structure and population dynamics for this species compared to monomorphic species such as tunas. The dimorphism may influence mate competition or mate choice, potentially disrupt the mating system, and negatively affect population growth when exploitation is intense (Rowe et al. 2003).

Possible territorial behavior and a harem mating system have been speculated for dolphinfish, with large males defending groups of females (Mesnick, Hastings, and Kraul pers. comm.). Sex ratios are often skewed towards females under floating objects (Oxenford pers. comm.). If dominance hierarchies exist for dolphinfish where males are defending territories as part of the mating system, exploitation may disrupt the small-

scale social structure. Spawning may be reduced because of the need to continually reestablish the dominance hierarchy and females may take longer to evaluate the quality of males (Rowe et al. 2003). If delays in releasing eggs occur for batch spawners like dolphinfish, egg viability can be greatly decreased (Kjørsvik and Lønning 1983; Kjørsvik et al. 1990 cited in Rowe et al. 2003).

Knowledge of reproductive biology is important for fisheries managers to assess conservation risks and to design management strategies (Rowe et al. 2003). Examining the possibility of an atypical mating system and biased sex ratios at sea will be helpful for stock assessments upon which management is based.

Objectives and goals

The objectives of this paper are to document sexual dimorphism of recreationally caught dolphinfish in the Southern California Bight and correlate the development of external features with gonadal development. My goals are threefold: first I describe a pilot study and report preliminary results on sexual dimorphism and maturity stages. Second, I correlate the sexual dimorphism results with the sexual development and finally, I discuss these results in the context of management of pelagic species and implications of the mating system for management. My goal is to incorporate this information into a larger project proposed by Dewar (pers. comm.) and the National Oceanic Atmospheric Administration (NOAA) Southwest Fisheries Science Center (SWFSC).

Materials and Methods

Sampling

Samples of *Coryphaena hippurus* were collected off the coast of southern California and northern Baja California during August, September, and October 2006. Scientists onboard recreational fishing vessels collected a total of 58 specimens (35 males and 23 females) using hook-and-line. The fish were identified as *Coryphaena hippurus* based on the small oval shape of the tooth patch on their tongue compared to the broader square tooth patch of the only other dolphinfish species, *Coryphaena equiselis* (Collette 1995) (Fig. 1). In some cases vertebral counts were also taken to verify species identification. *C. hippurus* has 31 vertebrae, whereas *C. equiselis* has 33 vertebrae (Palko et al 1982). Sex was determined visually by head shape (females with sloping heads, males with blunt heads) and/or gonad observation.

Morphological Measurements

Fork length (FL) of each fish was measured to the nearest 0.1 cm immediately after capture (measurement #1, Fig. 2). Other morphological measurements of head shape were initially attempted at sea, but proved to be difficult. Consequently, fish heads were removed at sea and stored frozen for analysis in the laboratory. A flexible measuring tape was used to measure three specific features of the head to the nearest 0.1 cm. The length of the longest dorsal-fin ray was measured from its insertion point to its distal tip (measurement #2, Fig. 2). The linear distance from the tip of the upper jaw to the insertion point of the first dorsal-fin ray was measured (measurement #3, Fig. 2). Finally,

the contour of the head, from the tip of the upper jaw to the insertion point of the first ray of the dorsal fin was measured along the midline (measurement #3b, Fig. 2).

Head measurements were taken twice and any measurements that were not within 5% of one another were measured a third time. The values of the second round of measurements were utilized except for instances where a third measurement was necessary. In these cases, the third measurement was utilized. In instances where the dorsal ray was damaged, measurements were not possible. Contour head length was not measured for the first six samples due to adverse sea conditions, which prompted the modification to the sampling protocol.

Gonad Collection, Preservation, and Analysis

Gonads were removed from the body cavity of fresh fish, and sex was determined based on visual appearance. Females had round, enlarged ovaries that ranged from bright yellow to red in color, with eggs visible to the naked eye. Males had laterally compressed, narrow testes that ranged from white in color to dark pink. A portion of one or both gonadal lobes was removed from the center of the lobe and preserved in 10% buffered formalin solution and later weighed to the nearest 0.001g. The remainder of each gonad was stored frozen in a labeled zip-lock bag. Frozen gonads were thawed, blotted dry and weighed in the laboratory on a Mettler balance to the nearest 0.01g. Weights of preserved and frozen samples were combined to estimate the total weight of the gonad.

A gonosomatic index (GSI) was calculated as gonad weight (g) x 100/body weight (g). Body weights were estimated based on the length-weight relationships of Zúñiga-Flores (2002) from samples captured in the sport and artisanal fisheries in Mazatlán, Mexico. The weight was calculated as, $W = 1.28 \times 10^{-5} FL^{2.9}$ kg for the males and $W = 3.4 \times 10^{-5} FL^{2.64}$ kg for the females (Zúñiga-Flores 2002).

Preserved gonads were subsampled and sent to an outside laboratory, where they were embedded in paraffin, sectioned at 6 μ m, mounted, and stained with Harris' haemotoxylin followed by eosin counterstain (Humason 1972). Histological sections were examined under a compound microscope to confirm sex and reproductive status.

For this project, the primary purpose of examining the gonads was to determine if the fish were mature or immature. Female maturity state was classified following the criteria of Hunter and Macewicz (1985) as modified by Schaefer (1998). Mature and active females were identified by the presence of postovulatory follicles, hydrated eggs, and/or advanced yolked oocytes from the most developed batch of oocytes in the ovary.

Male maturity state was classified following the criteria of Grier (1981) as modified by Schaefer (1998). Males were considered mature if histological evidence of sperm in the central sperm duct (vas deferens) was observed (Schaefer 2001). However, following these strict criteria, maturity state was undetermined for a few of the samples.

Results

Sexual Dimorphism: Morphological Measurements

A total of 58 samples, 23 females and 35 males, were examined for sexual dimorphism and sexual development. The morphological measurements show that the majority of males of any given size have larger head and fin features than the females. The length of the longest dorsal-fin ray from its insertion point to its tip illustrates that male dorsal rays grow at a faster rate and are larger than those of the females for similar size fish greater than about 80 cm (Fig. 3). Similar results were obtained for the linear length measurement (Fig. 4) and the contour length measurement (Fig. 5). Plotting the difference between the contour length and linear length distinctly demonstrates that the forehead of the males grows steeply, while the forehead shape of the female changes little if any (Fig. 6). A plot of the residuals of each morphological measurement shows more positive values for males and more negative values for females, further supporting the difference in head shape between the sexes (Fig. 7, 8, and 9). In the small size classes, males are similar to females and as they grow, males and females diverge in all three morphological features.

Histological Examination of the Gonads

Sex was identified based on the histological examination of gonads. This analysis was consistent with the field identification of sex based on head morphology and/or gonads.

Female Maturity State

All 23 females were classified as mature, based on the criteria of Hunter and Macewicz (1985) as modified by Schaefer (1998), because advanced yolked oocytes were present in the most developed batch of oocytes in the ovary. Hydrated eggs, which indicate that

spawning will soon occur, and postovulatory follicles, which indicate spawning had recently occurred, were observed in 9 of the samples. Hydrated eggs with no postovulatory follicles were observed in 2 of the samples and postovulatory follicles with no hydrated eggs were observed in 9 of the samples. Advanced yolked oocytes were the most developed stage in 3 of the samples. Female maturity state was compared with the linear length of the forehead and body size (Fig. 10) because the linear measurement was performed for all 23 samples. No trend in maturity state with size of the females was observed.

Male Maturity State

Of the 35 males, 31 were classified as mature based on the histological criteria of Schaefer (1998). This included evidence of sperm in the central spermatic duct (vas deferens). By strictly following these criteria, 3 of the remaining 4 were technically immature because the vas deferens appeared to be devoid of sperm. In all of 35 samples spermatozoa was observed in the seminiferous tubules. There are two possible explanations for the empty vas deferens for these samples. First, the sperm may have not yet transferred from the lobule to the central spermatic duct, in which case the fish were immature. Second, although spermatozoa were observed in the seminiferous tubules, the empty spermatic duct could have been an artifact of preservation of the gonadal lobe, and the fish were actually mature. As a result, maturity state was considered undetermined for the 3 samples that had vas deferens devoid of sperm. The fourth remaining sample did not have an obvious vas deferens, which may be due to an error in subsampling of the gonadal lobe, and maturity state was also considered undetermined.

Male maturity state was compared with the linear length morphological measurement and body size (Fig. 11) because the linear measurement was performed for all 35 samples. Samples were placed into one of three categories based on the fullness value of the vas deferens. Males with vas deferens less than 50% full of sperm were placed in the first category called “nearly empty”. Males with vas deferens greater than 50% full of sperm were placed in the second category called “nearly full,” and in the third category called “empty,” if the vas deferens was devoid of sperm. No pattern was observed between vas deferens fullness and size of the males (Fig. 11).

Gonad Weight and Gonosomatic Index

In both sexes, gonadal weights increased with body size for both males and females, but more steeply for females (Fig. 13). No relationship was observed between GSI and body size for either males and females (Fig. 14). The length-weight relationships used to calculate the gonosomatic index (GSI) of both males and females are shown in Fig 12. The males invested a small portion of their body weight to gonads, whereas the females invested a larger portion of their body weight to gonads. Male GSI values ranged from 0.31% to 1.37% while female GSI values ranged from 1.73% to 13.9%.

Discussion

Male and female dolphinfish have similar shaped foreheads in the smaller size classes. However as the fish grow, the male forehead shape changes at a greater rate relative to body size than that of the female. Similarly, the linear length and the contour length of

the male forehead increases as the fish grows whereas female foreheads remain slope-like as opposed to the steep forehead seen in the males. The dorsal-fin ray height increases with size in both sexes, but grows at a faster rate in the males than in the females.

Although these morphometric results are not surprising given that sexual dimorphism is well known in dolphinfish, it is surprising that the smaller males are mature even though their secondary sexual characters (head shape and dorsal-fin height) have not yet developed. Sexual dimorphism, therefore, does not appear to be correlated with sexual maturity.

Dolphinfish in the eastern north Pacific showed evidence of sexual dimorphism at approximately 60 cm FL. In other populations sexual dimorphism occurs at slightly smaller sizes; in the Straits of Florida steep foreheads were evident in males at approximately 40 cm FL (Beardsley 1967) and off the island of Majorca in the western Mediterranean at 40-50 cm FL (Massutí and Moralis-Nin 1997).

All fish, with the exception of the four males that had undetermined maturity, were sexually mature and active, including the males that did not possess the prominent forehead. Consequently, the size at maturity remains unknown for this population. Published accounts showed that the onset of maturity differs geographically for other populations of dolphinfish. In the Straits of Florida, Beardsley (1967) reported female maturity at approximately 35 cm FL with 100% mature at 55 cm FL, and male maturity at 42.7 cm FL. In the western Mediterranean, Massutí and Moralis-Nin (1997) observed that the size at first maturity was 47 cm FL for the females and 55 cm FL for the males.

The size at 100% maturity was greater than 60 cm FL for females and greater than 66 cm FL for males. On the east coast of Taiwan, Wu *et al.* (2001) found that size at sexual maturity of both sexes at approximately 51 cm FL, with 100% of females mature at 95 cm FL and males at 90 cm FL.

Gonad investment (GSI) is not correlated with body size in either sex across the site sampled in this study. Although gonad weights increased with size for both sexes, females increased at a greater rate relative to body size than males. The relative testes size to body weight is small, ranging from 0.31% to 1.37% across all size classes sampled in this study. This implies first, that dolphinfish have a polygynous mating system (Taborsky 1998; Mesnick and Ralls 2002; Perrin and Mesnick 2003) and second, that small males are not pursuing a different strategy such as sneak spawning which, with increased sperm competition, would predict larger relative testes size (Taborsky 1998). The larger males invest more in secondary sexual characters such as head shape and dorsal fin height and if males are defending territories of females, investment into gonads and sperm is expected to be limited (Taborsky 1998). While the mating system of dolphinfish remains unresolved, these results suggest male behavioral dominance and access to spawning females are important components to the mating system.

Behavior of dolphinfish in the wild has not been studied. However, aggressive behavior in captive male dolphinfish has been observed after about five months of age (Kraul, pers. comm.). While age was not determined in this study, a wild dolphinfish in Hawaiian waters is approximately 62 cm FL at 5 months of age (Uchiyama *et al.* 1986).

Aggression occurs even in males with slender heads, i.e., when head shape is indistinguishable from that of females (Kraul pers. comm.). Behavior in captivity further suggests male territorial behavior since, according to Kraul (pers. comm.), if more males are in the tank they will fight each other until only one remains. In captivity, spawning dolphinfish swim slowly together in tight circles and the males fertilize eggs from at least six females per day (Kraul 1991). Although captive behavior is not necessarily indicative of behavior in the wild, it is reasonable to assume the males are aggressive and territorial and that their bony crest functions in male-to-male competition, reflecting a social structure involving dominance.

In contrast to other species, such as tunas, sharks, cod, and swordfish, that are well known for their drastic declines due to over fishing (Myers et al. 2003), dolphinfish are currently not considered to be in danger (www.fishbase.org May 2007). However, recreational, commercial, and artisanal fisheries exploit dolphinfish. In Mexico, artisanal fisheries account for a significant portion of the dolphinfish catch, although according to the law, the ocean within 80 km of the coastline is reserved for sportfishing (Díaz-Jaimes et al. 2006). This area is also under consideration for opening dolphinfish to commercial fishery exploitation (Díaz-Jaimes et al. 2006). Locally, the CPFV fleet is economically valuable and the recreational catch of dolphinfish has increased in the past 30 years (Norton 1999). As fishing pressure on dolphinfish increases, it is important to understand their reproductive biology for effective management of the species.

Dolphinfish are different from other pelagic fishes in that they are strikingly sexually dimorphic, and knowledge of dolphinfish mating strategies is an unknown component of their life history. The large, blunt male foreheads and observations in captivity, imply that sexual dimorphism plays an important role in their mating strategy (Ralls and Mesnick 2002). If their mating system is in fact different from typical monomorphic species such as tunas, it is important for fisheries managers to understand this biology for several reasons. The potential territorial behavior and/or harem mating systems of dolphinfish likely increases their vulnerability to fishing pressure because intense fishing potentially disrupts dominance hierarchies, in addition to removing individual fish.

This research revealed intriguing insights into the sexual development of dolphinfish in the eastern north Pacific that can be helpful in determining management strategies.

Future research should include spatial and temporal expansion of the sampling protocol as well as increased sampling in the smaller size classes below 70 cm FL. Information on the population's size at first sexual maturity, size at 50% maturity, size at 100% maturity for the population, and knowledge of peak breeding season will also aid in developing effective management strategies.

In addition to research on sexual dimorphism and sexual maturity, the behavior of the species in the wild needs to be studied. In particular, we need to know about the dominance hierarchies, i.e., how are the hierarchies established, how stable are they, what is the turnover rate, and what happens when large individual males are removed.

We also need to know about the spawning behavior of dolphinfish, especially the potential spawning of small non-dimorphic males.

Sampling for this study was opportunistic utilizing fish caught on sport-fishing gear, which were more aggressive fish taking the hooked bait. Sex ratios tended to be skewed towards females and therefore, males were selectively chosen for sampling when available, as they were of particular interest for this study. The samples were mostly collected near the northern extent of their range, and may not be indicative of the population throughout the entire Pacific.

At present NOAA, SWFSC is interested in dolphinfish captured in the CPFV fleet due to its economic importance in the United States and Mexico and the lack of life history information on the species (Dewar et al. unpublished). Since dolphinfish are characteristically associated with floating objects, kelp cover likely increases their availability for CPFV anglers (Norton et al. 1994). Norton (1994) describes the most effective fishing methods that include casting live bait around floating kelp mats where dolphinfish tend to concentrate. The CPFV fleet provides a great opportunity to study dolphinfish and in particular their behavior under floating objects. Examining the possibility of an atypical mating system and biased sex ratios will be helpful for stock assessments upon which management is based. Knowledge of reproductive biology is important for fisheries managers to assess conservation risks and to design management strategies (Rowe et al. 2003). As there are neither management plans nor stock

assessments for dolphinfish in the eastern north Pacific, it is an opportune time to adopt an informed and precautionary approach to the management of the species.

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Figures:

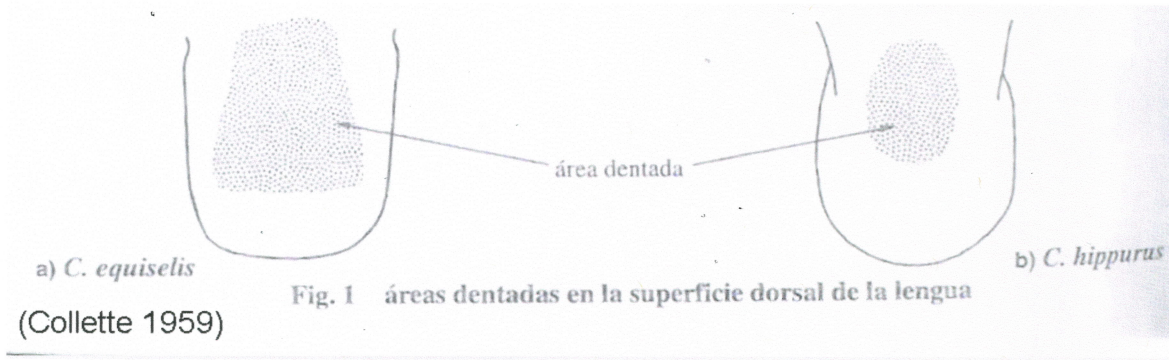


Figure 1: Distinguishing tooth patch on the tongue of each dolphinfish species, *Coryphaena equiselis* and *C. hippurus* (Collette 1995).

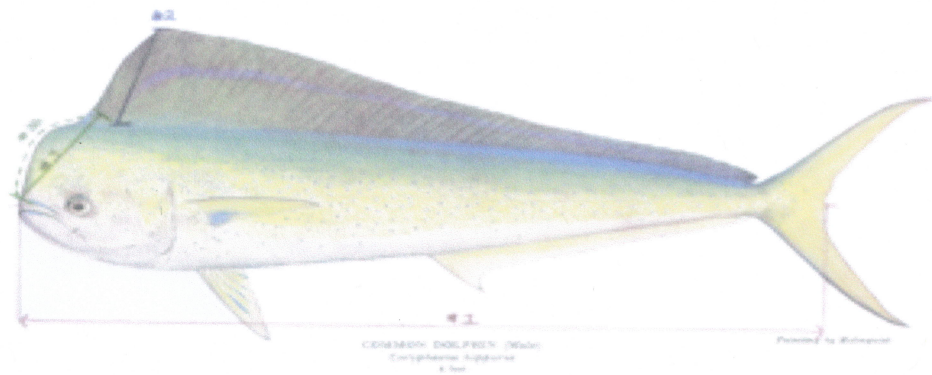


Figure 2: Diagram of the morphological measurements of dolphinfish taken in this study (Walford 1937).

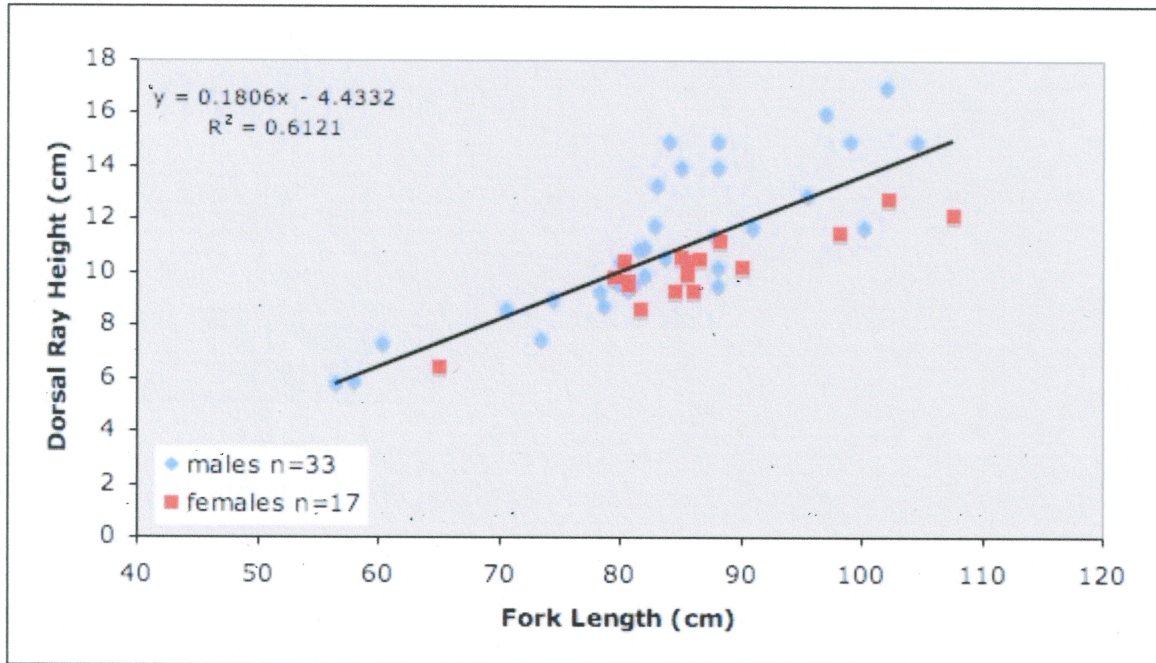


Figure 3. Height of the longest dorsal ray in male and female dolphinfish.

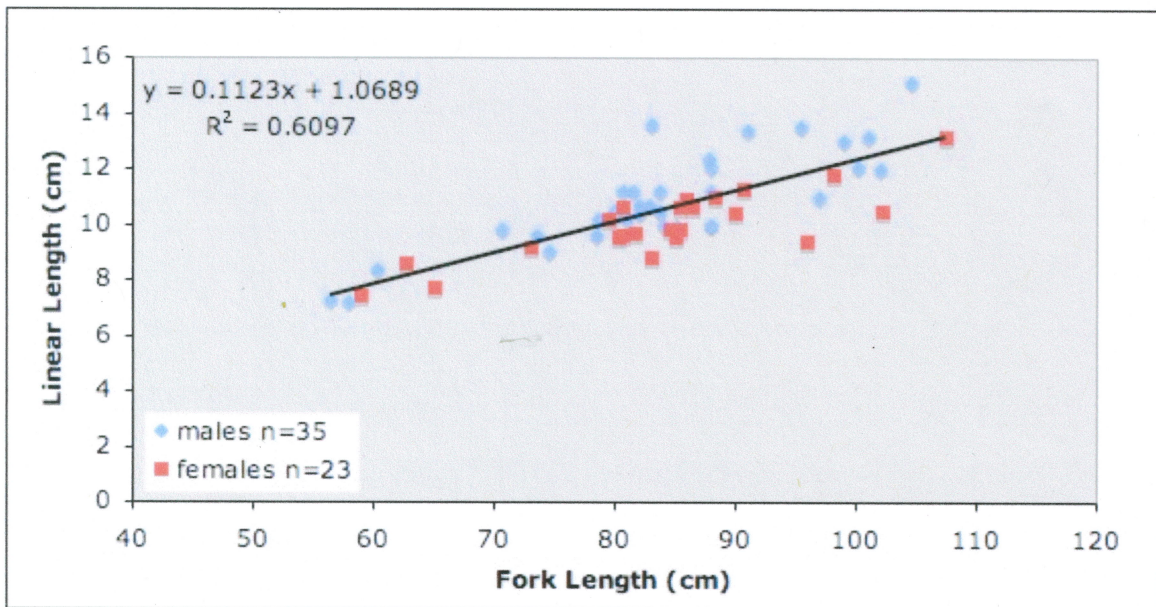


Figure 4. Linear distance from the tip of the upper jaw to the insertion of the first dorsal ray in male and female dolphinfish.

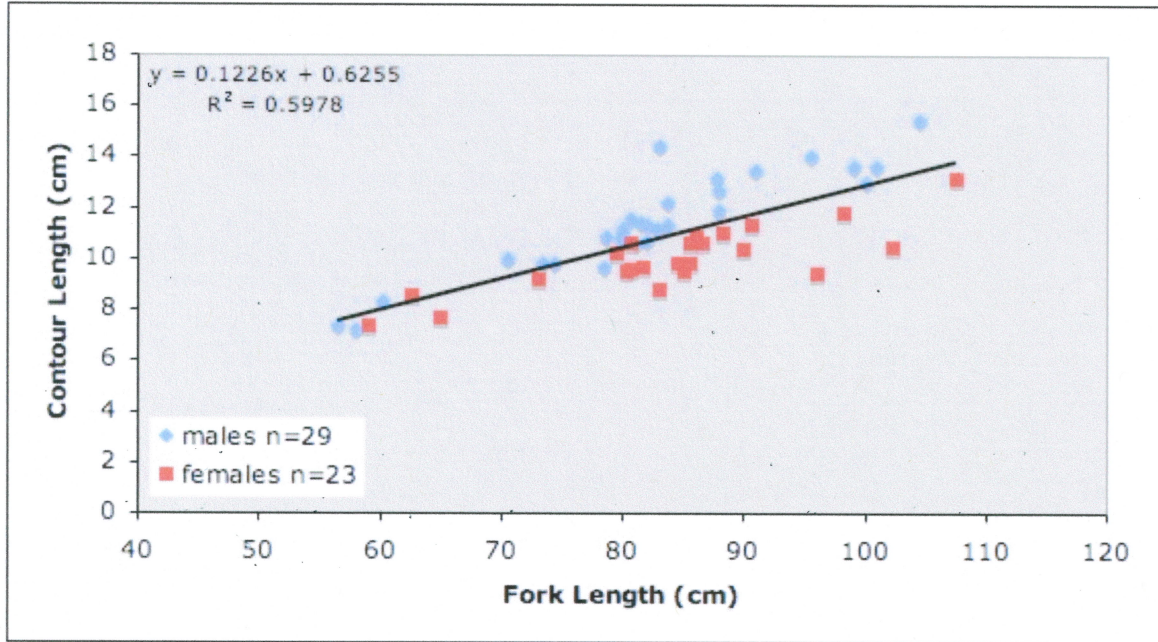


Figure 5. Contour distance from the tip of the upper jaw to the insertion of the first dorsal ray in male and female dolphinfish.

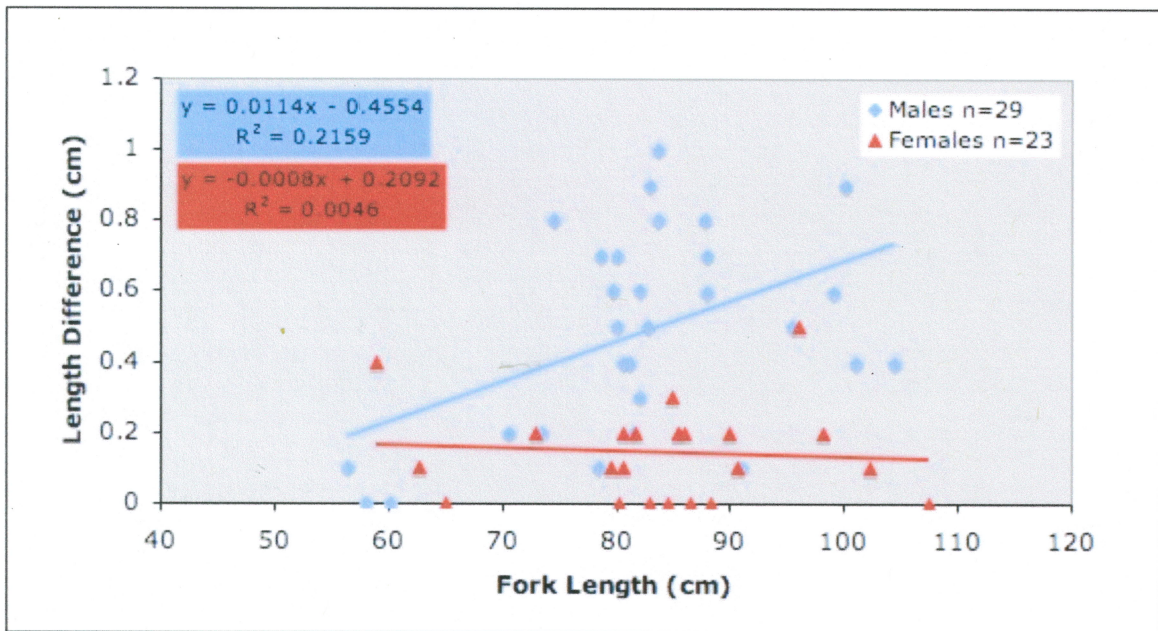


Figure 6. Difference between the contour length and the linear length of the forehead (see Fig. 2) of male and female dolphinfish.

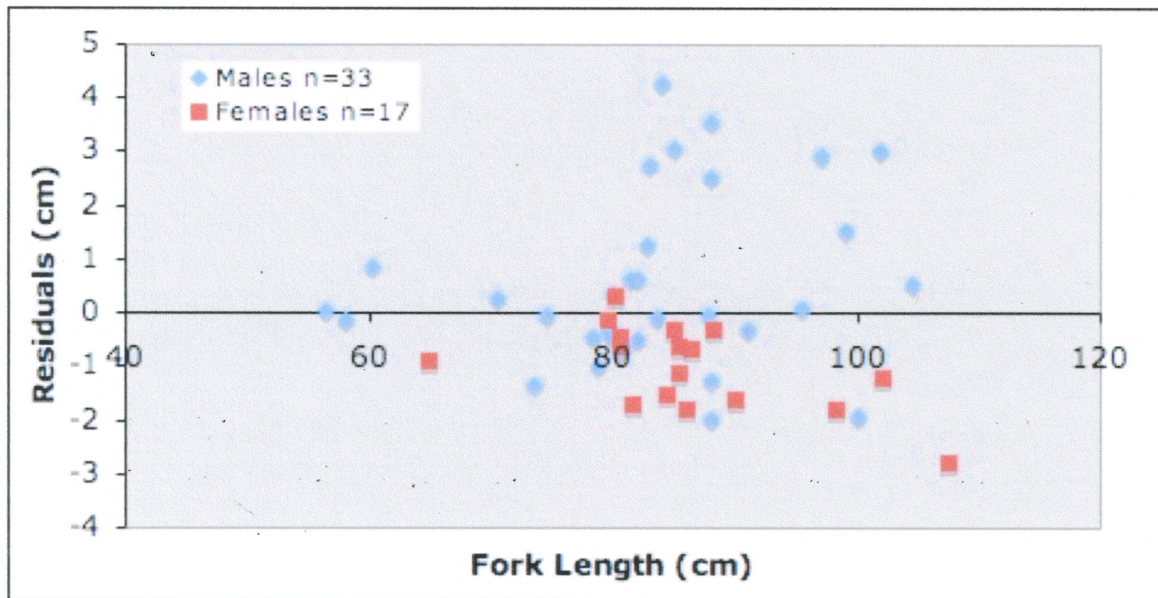


Figure 7. Residual plot of dorsal ray height (y) versus fork length (x) (see Fig. 3) $y = 0.1806x - 4.4332$ of male and female dolphinfish.

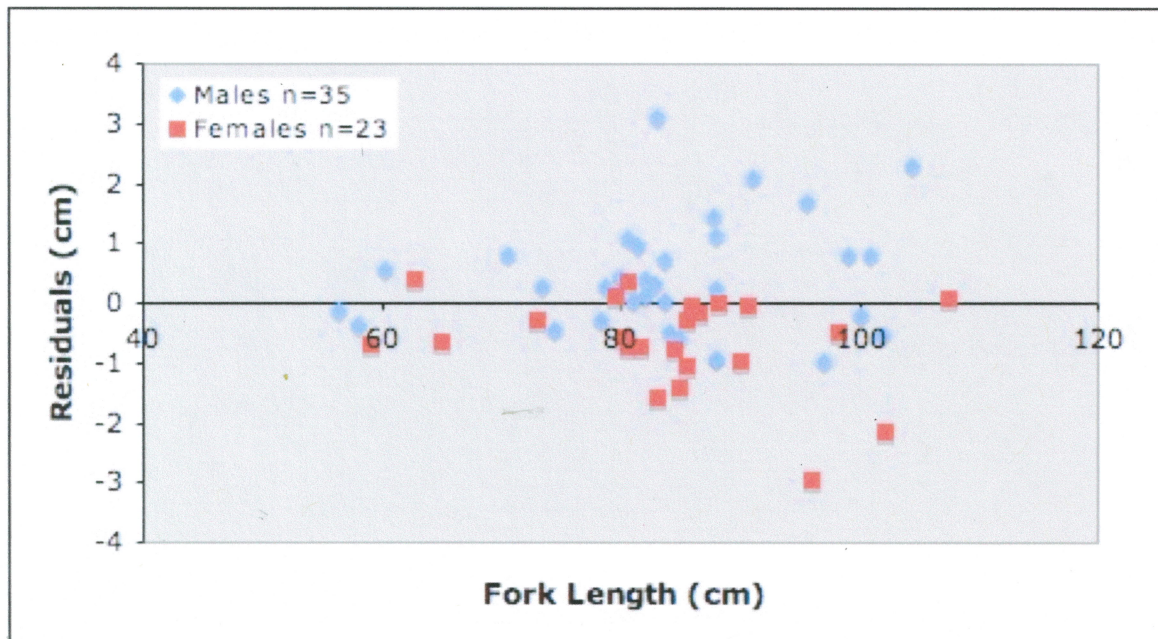


Figure 8. Residual plot of linear length (y) versus fork length (x) (see Fig. 4) $y = 0.1123x + 1.0662$ of male and female dolphinfish.

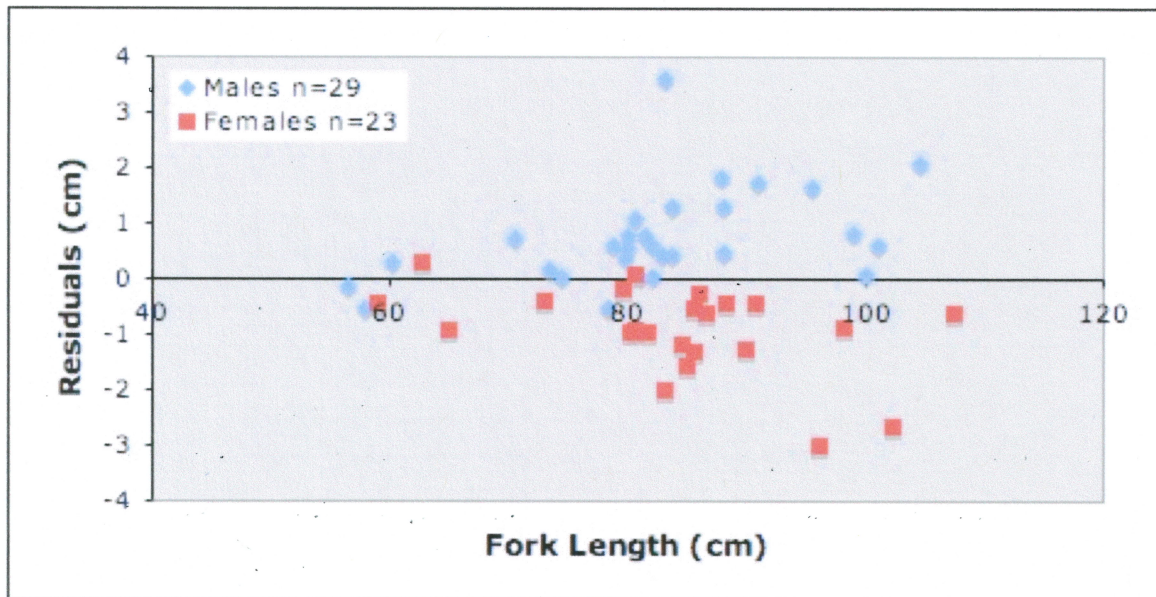


Figure 9. Residual plot of forehead contour length (y) versus fork length (x) (see Fig. 5) $y = 0.1226x + 0.6255$ of male and female dolphinfish.

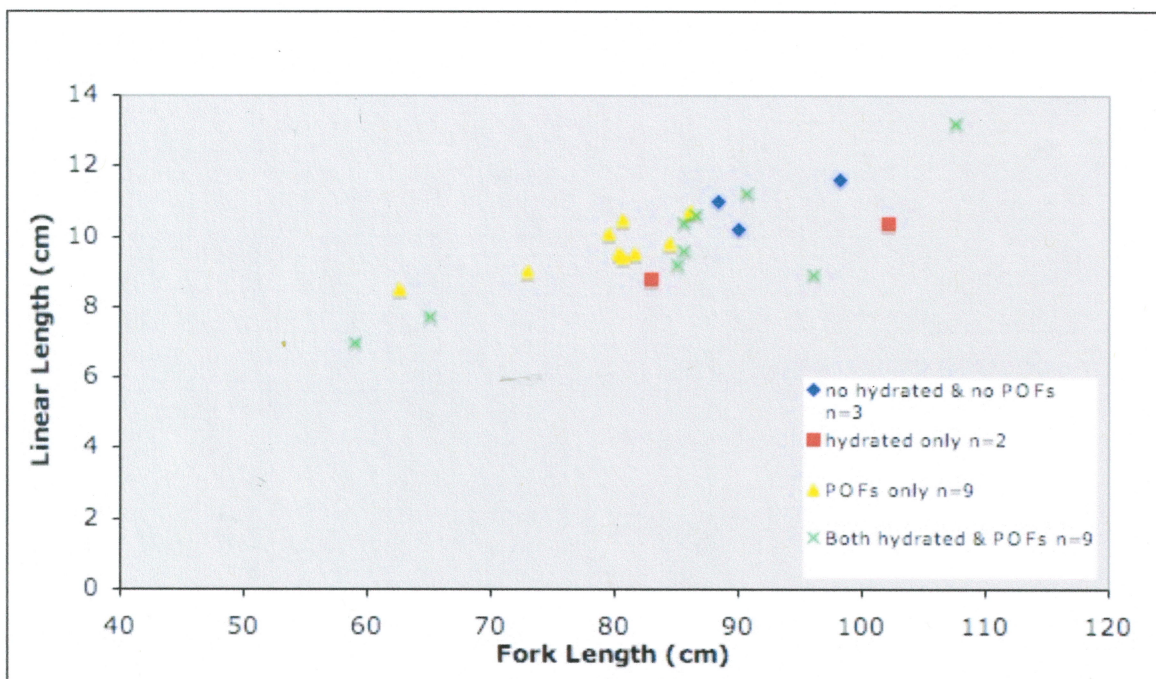


Figure 10. Linear length measurement of the female forehead (see Fig. 4) versus fork length comparing female spawning state of dolphinfish. POF: postovulatory follicle.

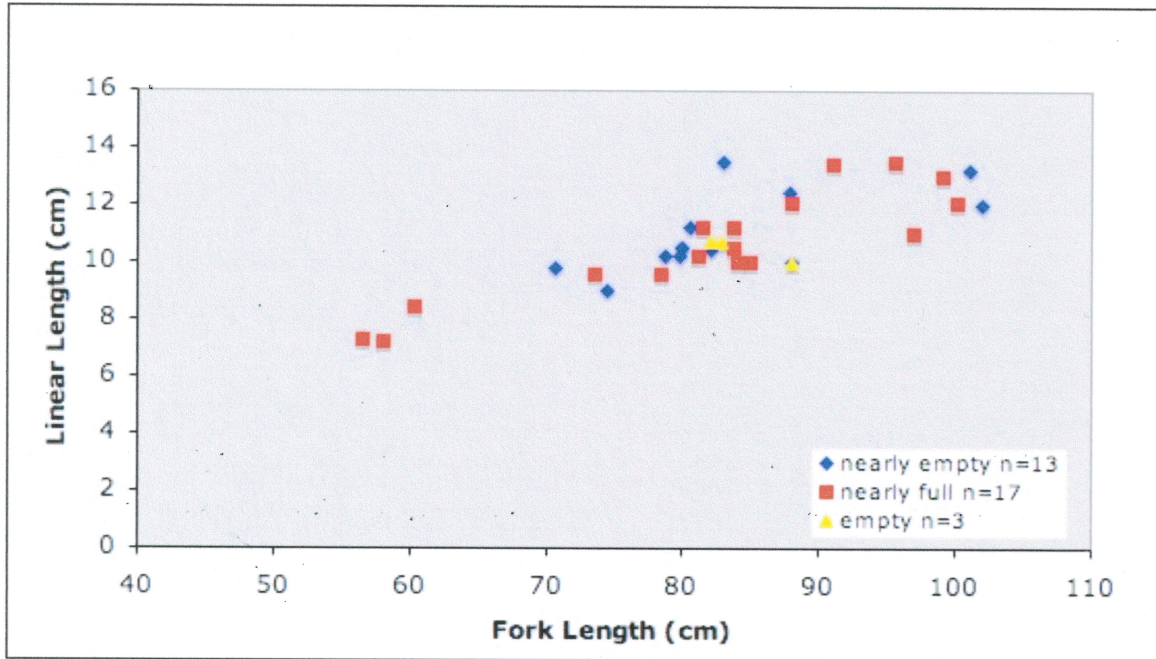


Figure 11. Linear length measurement of the male forehead (see Fig. 4) versus fork length comparing male vas deferens fullness of dolphinfish.

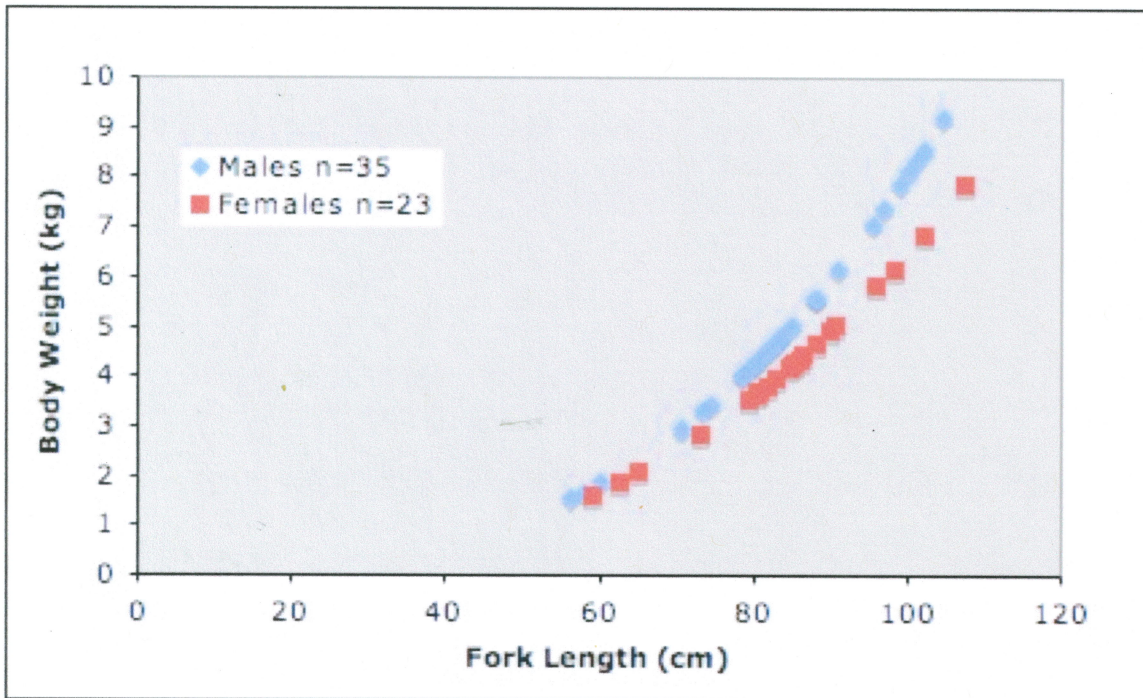


Figure 12. Estimated body weights versus fork length of dolphinfish based on length-weight relationships of Zúñiga Flores from samples captured in the sport and artisanal fisheries in Mazatlán Mexico (2002). The weight was calculated as $W=1.28 \times 10^{-5} FL^{2.9}$ kg for the males and $W=3.4 \times 10^{-5} FL^{2.64}$ kg for the females.

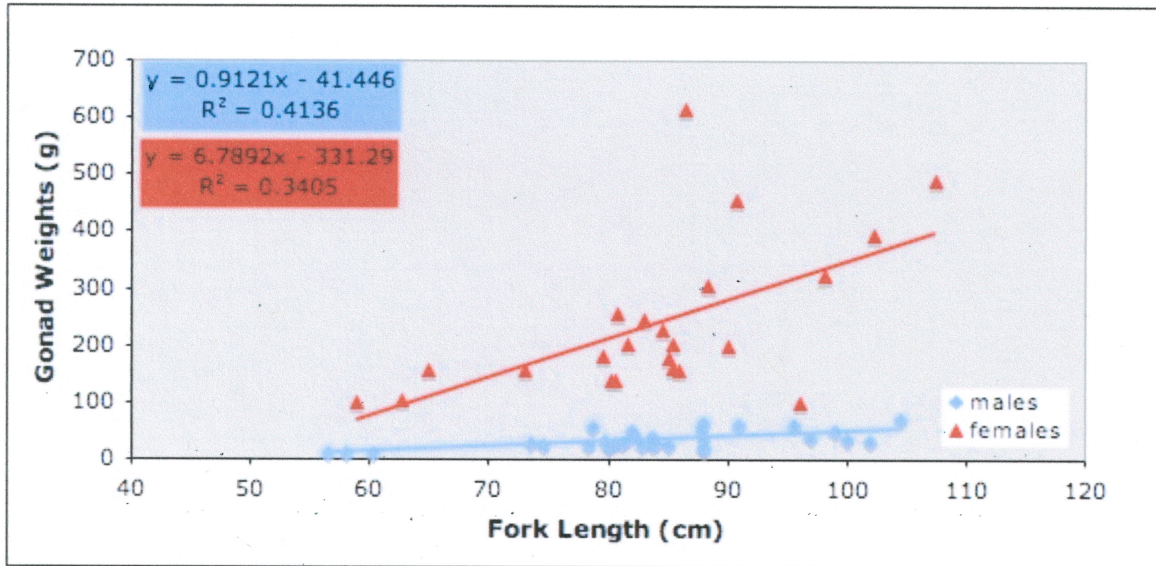


Figure 13. Gonadal weights versus fork length of male and female dolphinfish.

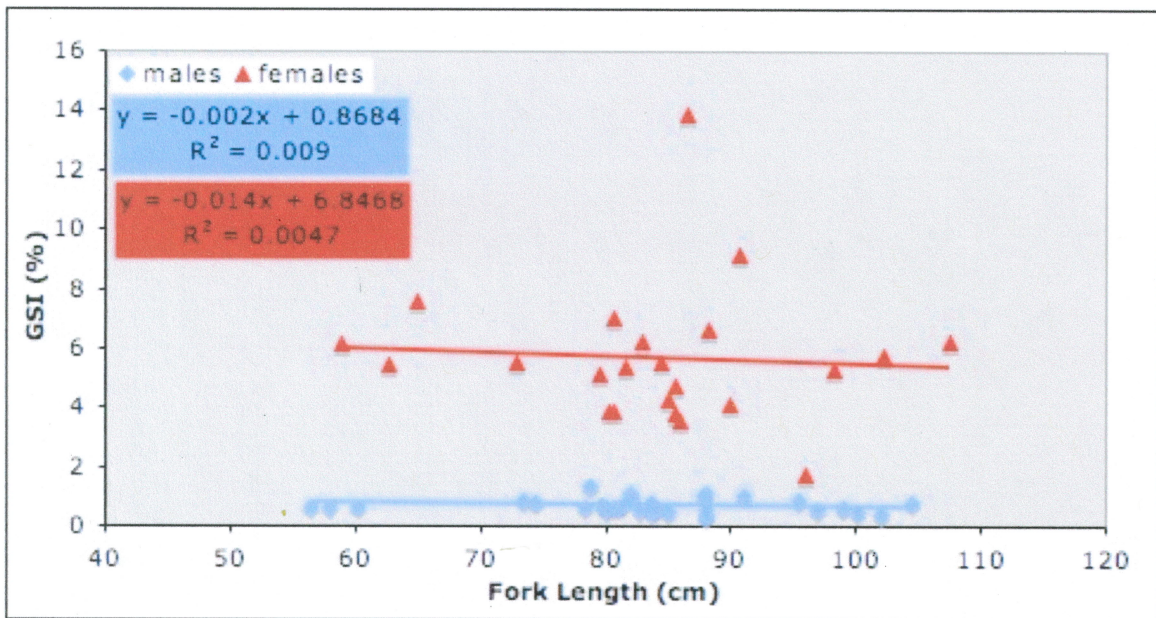


Figure 14. GSI values of male and female dolphinfish calculated as gonad weight (g) x 100/estimated body weight (g)