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March 24, 2008

Toby M. Gascon
Director of Government Affairs
Omega Protein, Inc.

Ref: Gulf of Mexico Menhaden: Considerations for Resource Management

Dear Mr. Gascon,

In response to your **Request for Scientific Analysis** regarding proposed regulations for menhaden fishing in Texas waters, herewith is our response to your questions. We have formatted it as a report. It includes a Preface, which sets the stage, an Executive Summary without citations, and a response to each of the questions with supporting citations. We have enclosed a copy of the paper (Condrey 1994) we believe was used by TPWD in drafting the proposed regulations. It has the appropriate underlying numbers and is the only study with sufficient detail to be used for the type of analysis attempted by TPWD.

We appreciate the opportunity to provide this analysis. It came at an opportune time. I have been developing the ecosystem material included in this document for many years, ever since the basic theory was proposed to me by a Russian colleague who went on to become the Soviet Minister of Fisheries. As Chief of the NMFS Research Division, I read countless documents regarding fisheries research and management, and attended many conferences and program reviews, slowly gaining the knowledge reflected in this report. The flurry of menhaden writings and government actions gave me impetus to complete the work, and your request accelerated it further. I expect the ecosystem materials in this present report will soon be part of a more-detailed formal scientific paper documenting the role of menhaden in coastal ecology.

Submitted by

John T. Everett

John T. Everett, President

Enclosure: Scientific paper, Condrey (1994), underlying bycatch aspects of the proposed rule

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Gulf of Mexico Menhaden: Considerations for Resource Management*

An analysis of certain aspects of a proposed menhaden fishery management rule by Texas Parks and Wildlife Department

March 25, 2008

Preface

Menhaden are an important part of coastal ecosystems and have a role whose importance we are only beginning to understand. We applaud the Texas Parks and Wildlife Department (TPWD) for recognizing that menhaden, like other clupeids, are omnivores (eat everything), and not just consumers of phytoplankton (plants). We also agree that menhaden eat their own eggs and larvae as noted by the department's statement:

> *"When considering predator-prey relationships, it is a key forage species for many other species in the gulf. Menhaden eggs and larvae are food for various filter-feeding and larval fishes and invertebrates including but not limited to themselves, other clupeids, chaetognaths, coelenterates, mollusks, and ctenophores."*

However, menhaden do not discriminate among the species they eat. It is particularly important to know what a fish eats when it is abundant, as is menhaden, because it can exert a controlling influence on other fish stocks that are less fortunate. Scientists who work with live menhaden have known they are omnivores for over a century. However, there has been an apparent disconnect between this knowledge and its application by the people to whom it is vital, including ecosystem modelers, stock assessment scientists, fisheries managers, and the public. If Texas restricts its menhaden harvest, the result will quite likely be decreased shrimp and gamefish populations. To the extent these populations using Texas coasts and estuaries as nurseries migrate beyond Texas, the proposed actions will impact the recreational and commercial fishermen in other states as well. This is why coast-wide management is so important.

The analysis that follows is derived from a dozen years of personal inquiry on "forage fish" species that are closely related to menhaden in both biology and ecological role. That work is nearing publication. Nevertheless, the science supporting this report is mostly specific to menhaden or is common to clupeid forage species.

*This paper may be cited as: Everett, John T. 2008. *Gulf of Mexico Menhaden: Considerations for Resource Management*. Report to Omega Protein, Inc. on proposed regulations. Ocean Associates, Inc. Arlington, VA. Available: http://www.oceanassoc.com/MenhadenTexasFull.pdf

Executive Summary

Recognition by the department that menhaden are omnivores is profound, with far-reaching implications that are rooted in the menhaden scientific literature. As omnivores, the juveniles and adults consume the larger phytoplankton (drifting algae) and all the zooplankton (small animals) they encounter. The zooplankton consists largely of animals that spend all or most of their lives carried by currents, eating the algae and each other. However, it also includes meroplankton, "temporary" plankton – eggs and larval and very young juvenile fish, shrimp, oysters, and crabs. Capture efficiency of larger organisms during filtering is high and nearly all that enters menhaden mouths are consumed. However, as any organism that loses a high percentage of its population every day to predation (probably about 10%/day for the first year), the menhaden are most abundant when they are larvae. Menhaden larvae eat mostly zooplankton in directed attacks and have teeth to help them capture their prey, which includes all zooplankton and virtually all fish eggs and larvae found in their presence. As stated by TPWD, menhaden are "*a key forage species for many other species in the gulf*". Likewise, many other species in the Gulf, during their egg and larval and smallest juvenile stages, are also forage for menhaden. Menhaden adults, swimming at two ft. per second with large open mouths, can each clear zooplankton (including fish and shellfish eggs, larvae, and small juveniles) from over 25 quarts of water per minute.

Traditional stomach analyses have not captured the extent of juvenile and adult menhaden's animal diet because of their extremely rapid digestion and their regurgitation of stomach contents during sampling. Putting the sampled animals on ice does not stop digestion, which is complete in a few hours, and quickly works through even the stomach walls and into the flesh. Recent menhaden diet studies using fatty acid composition and carbon and nitrogen isotope ratios, confirm menhaden to be primarily carnivores at all life stages. DNA analysis of already-digested stomach contents in herring (a close cousin) shows that young stages of predatory fish are part of their diet, even though they are quickly rendered invisible by rapid digestion.

In a balanced ecosystem, species adapt reproductive strategies to cope with variations in predation and other factors. Since menhaden predators are below virgin levels, unfished menhaden will expand to the limits that food, disease, and habitat will allow. These increased menhaden populations could well spell the demise of shrimp, red drum, blue crab, oyster and other populations whose youngest forms share space with always-hungry, always-feeding menhaden. This is particularly true of species that are at reduced levels, with reduced spawning potential. We wonder if menhaden's extensive predation on, and competition for food with, other species has been considered in this proposal.

In other documents that are part of these regulatory proceedings, we note that some people have the belief that menhaden are exclusively plant eaters. Nothing can be further from the truth. Fine scaled menhaden (*Brevoortia gunteri*) rarely or never eat plants and Gulf menhaden (*B. patronus*) eat only or mostly animals as larvae, and both plants and animals as juveniles and adults, with juveniles able to eat smaller forms of each. All menhaden species and all stages, primarily eat the animals that eat plants, converting them to ammonia-N, which fertilizes the waters, making them green and eutrophic. High menhaden abundance is part of the water quality problem, perhaps even leading to red tides and other harmful algal blooms. It is not the solution.

We do not yet know how many eggs or young sportfish, crabs, oysters and shrimp are eaten by menhaden in a day. However, since they are present where menhaden feed, competing for the same zooplankton, and since menhaden clear the water, it is likely that each menhaden eats several or many every day. Because menhaden filter all the water every few days in estuaries and coastal areas where they are abundant, they likely eat almost all that are there when they are. Of course, menhaden seek food where it is most abundant, usually near and in blooms of phytoplankton, so their filtering takes place where algae-eating organisms (e.g., zooplankton) are feeding. Most fish and shellfish larvae will also be in such areas, eating other zooplankton, each other, and some phytoplankton. While the youngest menhaden target individual prey, and there are billions upon billions of them, at some point during their juvenile stage they switch to becoming mostly or exclusively filter feeders. They continue eating zooplankton, and more phytoplankton (at first), just more effectively.

There is a defensive strategy in being in a school and there are hydrodynamic benefits. The most important benefit for a zooplankton filter feeder, however, is that schooling makes feeding on animals possible. Copepods, a primary food, can escape a one-on-one clupeid attack, but they tire easily. If there are many attacks in succession on copepods, as when a school of thousands or millions of menhaden passes through, all will be captured and converted to ammonia within about two hours. Sport and commercial fish and shellfish eggs, larvae, and young juveniles are also part of the zooplankton community and are present when a menhaden school moves through an area. Whether targeted individually by the young menhaden, or taken as part of the filter feeding strategy of older menhaden schools, virtually all that are size-appropriate will succumb and be eaten.

When it comes to bycatch, both scientists and regulators have long recognized that menhaden fishing, which takes place in shallow waters, catches few other animals and many, including most red drum, are released alive. However, TPWD is concerned that: “the total bycatch in Texas waters from the commercial menhaden industry is approximately 415,000 organisms per year.” There are several problems with this analysis, the most stunning of which is that someone forgot to move the decimal point when working with percents. There are other problems with the analysis, but this one correction would reduce the red drum number to 16 fish and also reduce the shark figure by 99%. Other analytical corrections, using the same study, show that the maximum Texas bycatch is 930 sharks and 28 red drum, and is likely less than half of these numbers. Of the total bycatch, croaker accounts for about half. There are several studies of menhaden bycatch in recent decades that have led fisheries managers to consider menhaden purse seining to be among the most selective of commercial fisheries. A study near Texas waters shows that total bycatch is less than a tenth of 1%, but TPWD has used 1%. We suspect the truth is in-between.

The Atlantic States and the Gulf of Mexico Marine Fisheries Commissions are the two fisheries management bodies that deal with menhaden management in the US at the interstate level. Both agree that menhaden bycatch is not a problem.

The bycatch issue should be put in perspective. The level of bycatch is negligible compared to the predation of menhaden on these same species of concern. An average menhaden can eat hundreds of organisms every day, and is just one of thousands or millions in a school. The school together can eat millions, including countless fish eggs and larvae. Thus a typical menhaden school eats far more than 415,000 organisms each and every day, a number that includes all the shrimp and sportfish organisms that are in the same areas and that will fit in their mouths.

If the objectives include water with less algae, and higher production of sportfish, the path does not include protecting menhaden from harvests. They are major predators of zooplankton and are competitors for them with the young of nearly all coastal fish species. In the presence of fisheries on predatory fish, a healthy fishery for menhaden that adjusts with changes in their naturally fluctuating population is the only way to maintain them in ecological balance. When out of balance, as will occur with a cap or prohibition, the menhaden will bloom until the ecological carrying capacity is reached. They will be at a higher level than when there were no fisheries for their predators. At this point, relatively few of the commercial and recreational species whose young require estuaries and coastal areas will escape predation. The young that do will have little to eat.

Menhaden harvests should be in balance with ecosystem function. Decades of fishing have provided valuable information about suitable harvest levels that will balance fishery and ecological needs and effects. Since stocks of menhaden predators are at reduced levels, menhaden populations would rise to such levels in the absence of a menhaden fishery that any depressed stocks having egg or larval stages would be insufficient to overcome menhaden predation. There needs to be balance among all the ecosystem components. Menhaden fishing benefits the menhaden industry, and the millions of Americans who rely on its products, and is far-reaching in economic impact. It also leads to improved water quality and is not a threat to other fisheries.

In summary:

- Menhaden are omnivores,
- Menhaden eat fish eggs and larvae of ALL species that are in the areas they frequent,
- Menhaden compete with all other larvae for zooplankton,
- Menhaden eat some smaller phytoplankton, at least as juveniles, and adults eat some larger phytoplankton, but all stages eat all the animals they can catch,
- Menhaden mostly eat the animals that eat plants, excreting them as plant fertilizer thus worsening water quality, and probably leading to harmful algal blooms,
- Menhaden fishing bycatch is among the lowest in the world, and
- “How many menhaden are enough” has more than one dimension.

As a postscript, it seems that the TPWD has over-reached in attempting to raise concerns about the importance of menhaden to our coastal ecology. We suggest that if it is important that menhaden be reserved as food for jellyfish, anemones and arrow worms, these common names should be used rather than (or with) their Latin names, as has been done for sharks and red drum. It might not evoke as much sympathy, but everyone would know the depth of the concern by TPWD for the welfare of the jellyfish, anemones and arrow worms, even if it means closing the menhaden fishery. In fact, menhaden are competitors of even these organisms.

Response to Specific Questions

The proposed rule contains the following statement:

The primary benefits of the proposed rule are: (1) protection of the menhaden population; and (2) protection of bycatch species. Menhaden is a primary component of the gulf estuarine marine ecosystem. When considering predator-prey relationships, it is a key forage species for many other species in the gulf. Menhaden eggs and larvae are food for various filter-feeding and larval fishes and invertebrates including but not limited to themselves, other clupeids, chaetognaths, coelenterates, mollusks, and ctenophores. Fishes known to eat menhaden include: the mackerels, bluefish, sharks, white and spotted seatrout, blue runner, ladyfish, longnose and alligator gars, and red drum. Piscivorous birds that have been found to consume menhaden include: brown pelicans, osprey, common loons, and terns. Marine mammals have also been reported as predators of menhaden.

In addition, the bycatch (the non-target species caught in menhaden nets and usually killed) from this fishery is also part of the ecosystem; thus, the impacts of menhaden harvest on other fisheries and the aquatic ecosystem must also be considered. The department estimates that at current harvest levels the total bycatch in Texas waters from the commercial menhaden industry is approximately 415,000 organisms per year. The top five bycatch species by number are Atlantic croaker (25%), striped mullet (17%), gafftopsail catfish (12%), silver seatrout (10%), and Spanish mackerel (9%) (in rank order of the catches with the approximate percent by number in parenthesis). Additionally, there are other key recreational species such as red drum and sharks. The approximate number of red drum and sharks mortalities associated with the current menhaden harvest is 1,600 and 31,000, respectively.

Questions:

1. The initial paragraph focuses on menhaden's ecological role as forage. On average, the Gulf menhaden fishery takes twenty percent of the population annually. Is there any science to suggest whether this level of harvest threatens this ecological role?

Menhaden stocks are at a healthy level, lying well within any definitions of "sustainable". They are not overfished and overfishing is not occurring, according to the latest report on the status of fisheries (Vaughan et al. 2007)[1] and the annual report to Congress on the Status of US Fisheries (NMFS 2006).[2] We agree with the statements on the Gulf States Fisheries Commission website that (1) menhaden are food constrained in the Gulf such that reduced fishing would not increase their abundance; (2) menhaden are but one of many prey items eaten by predatory fishes and birds and that they are second to bay anchovy in abundance; (3) they are "probably the most tightly monitored and managed fishery in the Gulf of Mexico. The menhaden industry has kept records of every single net set it has made since 1979 and provides these data directly to the National Marine Fisheries Service"; (4) that harvested at only some 20% of their population, they are not overfished; and (5) the lack of planktivorous fish is not the cause of poor water quality(GSMFC 2008).

In support of the statement of GSMFC (2008) that there are alternative prey to menhaden, we note that Knapp (1950) conducted stomach analyses on 5,946 fish of 34 species of "all the important game and food fish on the Texas coast. Menhaden were found in 165 stomachs with a frequency of 2.8 percent. Only 11 of the 34 species had eaten menhaden and in these the frequency of occurrence never exceeded 10.0 percent. The frequency of food items in the diet of these fishes was shrimp 61.8 percent, fishes exclusive of the menhaden 34.2 percent, crabs 12.0 percent, squids 4.0 percent, and miscellaneous invertebrates 4.4 percent."[3] Menhaden were less than 3% of the diet and the author stated that this may be an overrepresentation because their distinctive gizzards were slow to digest and more identifiable.

Oviatt (1977) [4]evaluated the fear of sport fishermen in Narragansett Bay that such a large portion of the biomass of menhaden was being taken by the industry that there was insufficient food for predator species. Her calculations showed "that even when menhaden abundances are so low that it is not commercially feasible to catch them, they are still sufficiently abundant to be a primary food source for predator fish."

An anecdotal indicator of the status of the menhaden resource is that it is not in the *Red List* of the International Union for Conservation of Nature and Natural Resources nor is there any record of it having been discussed (IUCN 2008).[5] This indicates that no one has raised concern about the stocks being in trouble to IUCN. The IUCN assesses "the conservation status of species, subspecies, varieties and even selected subpopulations on a global scale in order to highlight taxa threatened with extinction, and therefore promote their conservation".

We note that many people interested in fisheries have become concerned about reports that fish stocks in the Gulf of Mexico and around the world are overfished and that society has been "fishing down the food chain", taking fish from lower trophic levels. There was some very bad science done in making these assertions, by basing analyses on landings data. Of course, under fisheries management, if a stock, like cod or red snapper is overfished, landings are restricted by quotas during rebuilding and landings fall by design. This simple concept was not appreciated by the authors. Thus, regions like the Gulf of Mexico, which have sustainable fisheries for lower trophic level species such as shrimp and menhaden, were reported to be in danger because the ratio of high to low trophic level species (trophic level index) had fallen. Wherever catches of predatory species are restricted for rebuilding, while low trophic level fisheries on healthy stocks continue, it will appear the ratio has fallen. Since the shrimp and menhaden landings have remained relatively unchanged (with a natural variability) for decades, while the predator landings are restricted, it wrongly seems that more of the bottom trophic levels are being taken. In actuality we are just taking fewer of the high level fish, so they can rebuild. This is a good thing -- not the crisis relayed around the world. With specific reference to the Gulf of Mexico, de Mutsert et al. (2008) show that landings cannot be used to make these over fishing determinations because many "reductions in fishery catches were attributable to changes in regulations, market forces, or fishing effort",[6] and not the lack of fish as presented by the earlier authors.

2. One of the major issues raised by representatives of the TPWD and members of the public during the development of this rulemaking and in public comment has been the impact of menhaden on water quality. Specifically, the claim has been made that, as filter feeders, menhaden clean coastal waters and estuaries, thereby preventing red tides and anoxic zones. This is the central theme of H. Bruce Franklin's book, "The Most Important Fish in the Sea," and the claim has been repeated elsewhere. However, this runs contrary to our understanding of current science. For instance, the Atlantic States Marine Fisheries Commission's Amendment 1 to the Interstate Fishery Management Plan for Atlantic Menhaden states: "large school of menhaden can also deplete oxygen supplies and increase nutrient levels in the vicinity of the school. Enrichment of coastal waters by large numbers of menhaden can be expected to stimulate phytoplankton production. Oviatt et al. (1972) measured ammonia concentrations (from excretion) inside menhaden schools that were five times higher than ambient levels 4.5 km away. At the same time, chlorophyll values increased by a factor of five over the same distance, indicating the grazing effect of the fish on the phytoplankton standing crop." Amendment 1 at 10. We also understand that Durbin and Durbin have done perhaps the most comprehensive work in terms of ecosystem impacts of menhaden, and have come to similar conclusions.

Could you please provide us with the current state of scientific research on this question?

Menhaden are omnivores, with a focus on zooplankton as larvae and as adults, and perhaps a higher proportion of phytoplankton during some part of the relatively short period they are juveniles. With such a diet, they will contribute to poor water quality, not improve it.

The view of menhaden as exclusive phytoplanktivores persists despite overwhelming evidence that they are omnivores, with most energy being derived from other than plant life. Ecological modeling of their role too often assumes they are primarily phytoplankton eaters, even when it is acknowledged they do eat zooplankton (e.g., Lynch et al. 2006).[7] It is possible this is done because it is a much simpler task and to have a more complex situation would be untenable for the small budgets allocated to fisheries and water quality modeling studies. Mostly, though, it may be that it is the "common knowledge" and some feeding studies have assumed menhaden are plant eaters and have only tested various phytoplankton, which they will eat if of the appropriate size. It is analogous to having humans served lettuce and broccoli. We will eat it, but many of us would prefer to have it with steak, particularly if it comes in the same grocery bag. Scientists who actually work with menhaden (as opposed to modelers and mathematicians) have known since at least the 1800s that they are omnivores, with the observation by James Peck (1893) that adult menhaden are indiscriminate in their filter feeding and eat materials in the proportion to which they occur.[8] Somehow, an increasing chasm has developed in what is known by the field biologists and what is known by everyone else working with, or interested in, menhaden. Mr. Franklin's book has widened this gap.

Filter feeding is too-often misunderstood and this is at the root of some inappropriate research, regulations, and legislation. Filter feeding is a way of catching food. It does not mean that this food is necessarily plants, or exclusively plants, or small, nor that there is not targeting of individual items, nor that if something other than a plant or a copepod is filtered, it is spit out.

The largest whales are filter feeders, and some focus on large fish, but plants are not in their diet. None of the zooplankton community are immune from an always hungry menhaden with a large mouth that swims rapidly, or millions of its closest friends swimming together in a school. Durbin and Durbin found that adult menhaden gill rakers are optimized for the size of adult copepods, which they can filter at about 70% efficiency versus 25% for large phytoplankton, while swimming nearly 2 ft/sec. They also showed that menhaden eat large phytoplankton and zooplankton, excreting them as ammonia-N, which fertilizes the water and makes more algae (Durbin and Durbin 1998).[9]

Menhaden feed mostly on zooplankton at their youngest and at their mature stages, and perhaps all stages. For most of their lives they are optimized for eating zooplankton, animals that feed directly on phytoplankton or on even smaller animals that do. By eating zooplankton, and excreting them as fertilizer, algae density, particularly of the problematic small sizes is increased. Ted Durbin, noted menhaden scientist, said in November, "the role of menhaden in filtering plankton from the [Narragansett] Bay is more complicated than many people realize. By filter-feeding, menhaden reduce zooplankton populations, but such reductions allow phytoplankton to bloom. Also, he said wastes excreted by menhaden support phytoplankton growth." (Lord 2007)[10] The key points of his presentation (Durbin 2007) [11] were:

- The effect of menhaden grazing on small phytoplankton is negligible because of low filtration efficiency on small particles
- Large populations of menhaden will reduce zooplankton abundance, allowing phytoplankton blooms to occur
- Nutrient release by menhaden will enhance local phytoplankton growth
- The effect of menhaden grazing on larger phytoplankton and zooplankton, and their nutrient release, will favor smaller phytoplankton

Stoecker and Govoni (1984) offered both phyto and zooplankton to menhaden larvae, and demonstrated that larval menhaden are selective feeders and will consume the largest zooplankton they can catch. They will eat some phytoplankton, but also eat tintinnids and copepods and other organisms that eat plants.[12] Several studies have examined the physical attributes of menhaden gill-rakers at different life stages and estimated their selectivity for different food items and the efficiencies with which these might be filtered, showing that as they grow, they shift to larger planktonic organisms (Friedland 1984, Friedland 2006).[13],[14] June and Carlson (1971) found that larval menhaden are strict zooplanktivores, with a high preference for copepods, changing to a diet that includes phytoplankton as they lose their teeth during the juvenile stage, and that juveniles can filter smaller zooplankton than are eaten by the larval stage.[15] Kjelson et al. (1975) found that the diet of post larval juveniles was ~99% copepods of several species.[16] Further developmental changes occur as menhaden pass into adulthood, enabling them to filter copepod-sized articles most efficiently, to the point that each adult can clear 24.8 liters/min of copepods (Durbin and Durbin 1975).[17]

The menhaden remove both the zooplankton and the large sizes of phytoplankton needed by many young fish and larger zooplankton, creating a void in food needed by many organisms in their critical path to development. Menhaden are most numerous when they are larvae, have teeth, and cannot filter feed. When they are adults, they have minimal capability to filter algae. In between, as juveniles, research shows they can eat mostly (99%) detritus and algae when in creeks and marshes (Lewis and Peters 1994),[18] or mostly (99%) zooplankton when away from the marsh areas (Kjelson et al. 1975),[19] which is most of the time. By analyzing fatty acids in juvenile menhaden. Jeffries (1973, found that 70% of stomach contents were zooplankton.[20] *Brevoortia patronus*, Gulf menhaden, when compared to *B. gunteri*, finescale menhaden, have a finer mesh, "which enables it to select both small and large food items", whether plant or animal. In Mexican estuaries, 91.9% of *B. patronus* stomachs had some zooplankton with 28% of their diet consisting of zooplankton (Castillo-Rivera 1996),[21] likely reflecting its proportion of the plankton assemblage at that location.

Friedland et al. (2006) suggest that as menhaden grow in size in preparation for leaving the estuary and becoming migratory adults their filtering apparatus becomes coarser and they lose or lessen their ability to catch the smaller phytoplankton, but not the larger, because the fine spacing would be a hydrodynamic burden.[22] Recent research shows quite definitively that menhaden are predominately zooplanktivores as adults, or at all life stages (Smith and Jones 2007, Brush et al. 2007).[23], [24]

3. We note with interest that the rule states that menhaden prey on their own eggs and larvae. On balance, it seems that a fishery on adults would, to some degree, lessen mortality and improve survival opportunities of juvenile menhaden, particularly given how efficient menhaden are as filter feeders. We note that the Gulf States Marine Fisheries Commission states: "The total gulf menhaden population is limited by available food, space, and habitat. Elimination of the reduction fishery will probably not result in a substantial population increase in the Gulf." Can you provide any scientific insight into these issues?

Menhaden adults swim in schools, not only to reduce predatory attacks and increase hydrodynamic efficiency (e.g., Pitcher 1986)[25] but also to exhaust their own prey, so that fish further back in the school can catch them, if they don't (Kils 1989).[26] No laboratory feeding studies are known to have considered this, yet copepods, the primary zooplankton, can nearly always escape a one-on-one encounter with a planktivore, but not a school of them. Planktivores select food based on visual factors such as size, visibility, color, shape and motion. When prey is dense enough, selection is based on size, due to the higher energy content and visibility. Copepods can sense an oncoming predator and accelerate in a few milliseconds to 500-1,000 body lengths /sec. for a few seconds, leaving it with only a 7-24% chance of capture, per encounter. Their reaction time to avoid predation is very similar to the capabilities of planktivorous fish to capture copepods (Strickler et al. 2005).[27]

Since menhaden are abundant, well within their natural variability levels, they can suppress zooplankton populations dramatically, depriving fish larvae, including sportfish and their own, of the ability to find food. Zooplankton is the primary food source of most fish larvae and also adult menhaden. Menhaden adults have been shown to reduce zooplankton populations, and in other areas, younger stages of other clupeids have been shown to consume much of the available zooplankton supply. In the coastal Baltic Sea, for example, young-of-year herring alone account for 35-60% of the zooplankton consumption (Springer and Peckman 1997).[28] Rapidly consuming all the food available, menhaden can become measurably density-dependent - they are smaller and thinner for their age. Since the GSMFC states that the menhaden resource is constrained by available habitat and food, there is little doubt that menhaden are always searching for additional food.

The egg and larval stages are the most vulnerable for any fish. Predation is high and constant nutrition is mandatory for larvae. With few fat reserves, food must be constantly available. This is particularly important when, as GSMFC has noted above, menhaden themselves are food constrained. Menhaden are among the few fish that can, at some point in their lives, feed on all sizes of zooplankton, from the nearly bacteria-sized animals when they are juveniles to nearly all larger zooplankton, at all menhaden life stages. They can create a bottleneck in the ability of many species to find food. The fact that correlations have not been built between the size of adult menhaden populations and the amount of young menhaden is likely due in part to their self regulating nature. Poor recruitment may not be a sign that there are too few spawning adults, but rather, all things being equal, that there are too many juveniles and adults. When adults are numerous they prey on and compete with their own young – as well as those of all other suitably sized animals. Poor recruitment is not a sign of impending trouble if stocks of spawning adults are high. More is not always better.

4. The numbers used to estimate bycatch appear to be particularly suspect. We have a series of question and concerns.

A. The estimate of total shark bycatch in the Texas component of the Gulf menhaden fishery (which accounts on average for 3% of total Gulf harvest) is wildly at odds with estimates used in the National Marine Fisheries Service's shark assessment. In the SEDAR 11 Stock Assessment Report for Large Coastal Shark Complex, Blacktip and Sandbar Shark (2006), Table 2.2 shows a total of 20,200 sharks caught in the entire Gulf menhaden fishery, while Texas is estimating a total of 31,000 taken in the Texas fishery alone. Texas produced its estimate by using an estimate that 15% of the bycatch in the Gulf menhaden fishery is comprised of sharks that apparently is derived by a 1994 study by Richard Condrey and Janaka de Silva. However, de Silva is responsible for the most recent shark stock assessment figures. Can you explain the different results and the relative scientific merit of the Texas estimate?

B. More broadly, the bycatch estimates were derived from this and perhaps other studies by Condrey and de Silva. We understand that one of the findings of their bycatch studies was that bycatch rates were significantly higher in the eastern part of the fishery (i.e., eastern Louisiana and Mississippi) than catches made in the western part. Would you please review the methodology used by Texas to arrive at its estimates, and provide an opinion as to the soundness of the estimates and how well they comport with the science upon which they are based? Some background materials on the estimates' derivation are attached.

As further background, it also appears that bycatch in the Gulf menhaden fishery is extremely patchy, with many sets containing no or extremely little bycatch, and a wide variety of species caught in sets containing bycatch. There is also a discrepancy in the record as to whether the rate of shark and red drum is 15% and 2%, respectively. As the Texas biologist who derived the estimates stated at one point: "While sharks and red drum did not occur in the retained

samples, sharks accounted for 0.15% and red drum accounted for 0.02% of released bycatch species by number of sightings, and sharks accounted for 0.07% and red drum accounted for 0.005% of the bycatch species in the released bycatch." These obviously are significant discrepancies. It is also unclear to us how Condrey's and de Silva's distinction between "released" and "retained" bycatch apply to estimates of overall bycatch rates.
Any light you can shed on these issues would be greatly appreciated.

If the TPWD is concerned about bycatch, and about red drum or other sportfish abundance, we suggest it seek improvement in other fisheries. The literature shows that in some Texas recreational and commercial fisheries the amount of bycatch is more than the targeted species, whereas in all the menhaden bycatch studies, it has never exceeded a few % and is most commonly at or below 1% (Austin, Kirkley and Lucy (1994) for Mid-Atlantic bight - 0.041%,[29] Condrey (1994)[30] for Alabama-Louisiana -1%; Guillory and Hutton (1982)[31] for W. Louisiana - 1.3%; and Knapp (1950) [32] for W. Louisiana – 0.07%.

Since the effort to restrict menhaden fishing is being led by the recreational sector, it is instructive to review its bycatch statistics. A thorough analysis for Texas was done by Campbell and Choucair (1995),[33] who found that recreational fishermen (on private boats) caught more than 3 million bycatch fish, some 200% more bycatch than the fish they kept, and that it consisted mostly of spotted sea trout, red drum, red snapper and catfish. These were catch and release bycatch, for the most part, but hooking and handling mortalities for these fish range from a few percent to over 30% in many studies. For example only 10% of red drum are hooked in the esophagus, but half of these die. An excellent review of 18 of these studies, including four from Texas was done by *Burrage et al. (1997)*.[34] If we conservatively apply a 10% mortality to the 3 million bycatch fish (just from boats), it is clear that the number of red drum taken during menhaden fishing is rather small in comparison. Saul and Osborn (1992) estimated that private boats alone in just the Galveston Bay system, "released dead" an average of over 100,000 fish each year from 1979-1985. [35]

Further "quite a few sea turtles are hooked each year by recreational anglers" according to the Texas Parks and Wildlife (2008).[36] For perspective "*No sea turtles have been reported in Gulf bycatch studies"* (GSMFC 2002)[37] Pelicans are also hooked by recreational fish hooks and entangled in lines, and in some areas there are significant mortalities (USFWS 2008).[38] In comparison, menhaden fishing provides pelicans an easy lunch and they are almost always accompanying menhaden boats.

The TPWD states that "415,000 organisms are killed each year by menhaden fishing in Texas. The top five bycatch species by number are Atlantic croaker (25%), striped mullet (17%), gafftopsail catfish (12%), silver seatrout (10%), and Spanish mackerel (9%) (in rank order of the catches with the approximate percent by number in parenthesis). Additionally, there are other key recreational species such as red drum and sharks. The approximate number of red drum and sharks mortalities associated with the current menhaden harvest is 1,600 and 31,000, respectively."

We tried to replicate this analysis. We believe it used the species bycatch percentages from the Eastern Gulf as reported by Condrey (1994) and applied them to Texas waters. In the absence of any Texas data, this seems like a reasonable approach. That is, until you read what one of the study leaders (a graduate student of Dr. Condrey) said about their continued sampling work during a session of the GSMFC Menhaden Advisory Committee in 1996. His comments are included in their entirety:

"J. de Silva provided a characterization of the makeup and disposition of bycatch of the gulf menhaden fishery during 1994 - 1995. Bycatch percentages by set ranged from 0% to 4% during the study, with an overall average of 0.16%. Atlantic croaker and sand seatrout comprised the greatest percentage of retained and released bycatch by numbers and weight during the study, followed by spot and silver trout. Sharks and red drum were noticeably represented in released bycatch. Areas east of the Mississippi River produce more bycatch (numbers and weight) during menhaden fishing operations than do areas to the west. Species diversity of bycatch differs between areas east and west of the river, with western areas exhibiting richer species assemblages."(GSMFC 1996)[39] Thus, the author makes it clear that the species mix in the eastern Gulf is different than to the west.

There are five primary problems with the TPWD analysis.

Problem 1: The department states that "The top five bycatch species by number are Atlantic croaker (25%), striped mullet (17%), gafftopsail catfish (12%), silver seatrout (10%), and Spanish mackerel (9%) (in rank order of the catches with the approximate percent by number in parenthesis). However, these numbers were taken from Condrey (1994) and refer to the percent makeup of the retained bycatch catch by weight, not by number. It is taken from a sample of the pumped fish going into the hold. It does not include the big fish in the non-hold bycatch. It is not possible to use the percentages of bycatch *weight* multiplied by the *number* of fish in the total bycatch to establish the numbers of fish in the total bycatch. Since, for example, the average shark and red drum are large and cannot enter the hold and each weigh more than the average croaker (which are usually very small), such an analysis would be fundamentally flawed. Although presented in error, it is not clear whether this error was made in any calculations included in this proposed regulation. However, it may have been used to justify action *and* this regulatory proposal. A lesser problem is that this study considered any non-menhaden species to be bycatch, even though the various menhaden cousins (herrings) have similar properties as do menhaden. This inflates the % bycatch number and can create a problem where one does not exist. Fortunately, these other fish are only occasionally present, but when they are, it may be a whole school (e.g., of herring), distorting the reported amount of bycatch. Condrey reported that "the most striking feature of the retained bycatch samples is the highly skewed distribution toward no bycatch". The bycatches are so variable and the 50% of sets with zero retained bycatch so high, that one should not use averages to make projections.

Problem 2: "*Areas east of the Mississippi River produce more bycatch (numbers and weight) during menhaden fishing operations than do areas to the west*" taken from the de Silva quote above. While unquantified, but noticeable, the percentage of bycatch is likely appreciably below the already very low1% found in the eastern Gulf. This is borne out by Knapp (1950), in the study closest to Texas (in Western Louisiana), finding that "out of 2,500,000 menhaden taken in 17 purse-seine hauls in Louisiana waters over a 2-month period, 208 game and food fish comprising 12 species were caught….Therefore, a menhaden fishing industry should not interfere with sport or commercial fishing in the bays. Actually, such a fishery may be beneficial by its reduction of sharks and other undesirable fishes in the area."[40] Game and food fish bycatch in this study was 0.000000832% and total bycatch was 0.07%– a very selective fishery by any standard. Using Condrey's 1% bycatch estimate is inappropriate and this study is the better source if an estimate is necessary, particularly in light of de Silva's remarks about his own (with Condrey) study.

Problem 3: The calculation for the number of sharks and red drum has a 2 decimal point error. The corrected figures are 622 (415,000*.0015) sharks and 83 (415,000*0.0002) red drum.

Problem 4: The calculation of 0.15% for sharks and 0.02% for red drum represents the proportion of the observations of released bycatch in which these species were observed. It is not a ratio. For contrast, menhaden were observed in 100% of these sets; this does not mean that there were no other species in the catch. Condrey notes that of the released sharks, 50% were dead and for the red drum, 20%. He also shows that no sharks or red drum was retained by the vessel, either as part of its catch or as food for the crew. Further, the few released bycatch fish are negligible compared to the retained bycatch, consisting of those small items that fit through the large fish separator screen on the suction head of the hose and end up as part of the catch pumped with the menhaden. There were no sharks or red drum in this retained component of total bycatch. In fact, the total number of bycatch not going into the hold, which includes the sharks and red drum, is so small that Condrey states "if all the released bycatch were released dead, it would amount to an insubstantial increase in the bycatch to menhaden ratio computed here for the retained bycatch." Even so, only 20% of the red drum are released dead.

Condrey did not anticipate how his data would be used and this is part of the problem with the TPWD analysis. The statistics needed must be calculated. Fortunately, much of what is needed is in the Condrey 15 data tables. One of the key elements to determining if many sharks or red drum are getting killed is to know how many get killed each set and what proportion of the number of menhaden this is, since TPWD thinks this is important in establishing it as part of the 415,000 total bycatch they provide for Texas. Using the menhaden catch frequency distribution data of Condrey in Table 7, we can calculate that the average menhaden set in the study caught 44,980 standard menhaden (a standard menhaden allows conversion between numbers and weight and is established by NMFS through catch sampling).

From Table 14, we find that 201 sharks were observed during 63 of 127 sets (50%). From Table 15, half (49.8%) were released dead. The 101 dead sharks represent .002245% of the 415,000 Texas organisms or 932 sharks. Using the same tables. we find that 15 red drum were captured during 7 of 127 sets (0.05%). Of these, 3 (20%) were released dead. These 3 red drum represent 0.000006696% of the 415,000 Texas organisms, or 28 red drum. As noted above, the actual bycatch in Texas is likely much lower than this because Texas has a lower bycatch rate than the areas where the study was conducted, and for red drum, as pointed out in Problem 5, the fleet works with TPWD to avoid areas where red drum are in abundance.

Problem 5: In making a projection for Texas using the Condrey (1994) data, TPWD did not take into account the voluntary agreement whereby menhaden boats remove themselves from waters when TPWD finds red drum and notifies the owner. There was no such arrangement in the area Condrey data were obtained.

The menhaden fishery is one of the most selective in the world, with a small bycatch, of which croaker is the principal species (about half of all) and most others are not charismatic species. The menhaden fishery bycatch should be put in perspective. Juvenile Atlantic herring, a close cousin of menhaden, have been observed to find dense zooplankton patches of very evasive copepods in turbid water within 30 minutes of formation, consuming the school in 30 minutes, with individual fish eating 2.4 zooplankton/sec (Kils 1992).[41] In that 30 minutes, the average menhaden, among thousands in a small school would have eaten dozens or hundreds of organisms. The school together would have eaten millions, including countless fish eggs, larvae and very young juveniles that are included in the zooplankton. In Narragansett Bay, menhaden have been shown capable of significant reductions to the zooplankton population (Durbin and Durbin 1998)[42].Thus a typical menhaden school eats far more than 415,000 organisms each and every day and that at the state-wide level, the 415,000 organisms pales in comparison to the number of shrimp, oysters, crabs, and sportfish organisms consumed by menhaden every day in Texas. There are two sides to predator – prey relationships and these relationships are not completely separable from bycatch issues when making decisions.

Two management bodies deal with menhaden management and its coordination in the US at the interstate level: the Atlantic States and the Gulf of Mexico Marine Fisheries Commissions. The ASMFC states in their latest stock assessment report: "*Bycatch (or incidental catch) of other fishes in menhaden purse seines has been examined since the late 1800s. Taking of non-target species is a relatively rare event, and the overall bycatch is insignificant*." Among their references are menhaden bycatch studies in the Gulf of Mexico (ASMFC 2004).[43] The GSMFC, in its Plan states "*While bycatch reduction is a major issue in many U.S. fisheries, the U.S. Gulf of Mexico menhaden industry has used bycatch reduction devices since the 1950s. Large non-target species which are netted during the menhaden fishing operation can slow the pumping and damage pumping gear; therefore, attempts are made to remove large bycatch organisms from the net prior to this process. Currently the industry employs a hose cage designed to prevent the larger fish from being drawn up into the pump system and a large fish excluder which serves to prevent the passage of larger, non-target species from entering the hold*". The Plan cites 6 studies of menhaden fishery bycatch *(GSMFC 2002).*[44]

An EPA-funded report on Gulf fisheries, in which Texas Sea Grant participated, states *"Due to the way the gear is operated, the menhaden purse seine fishery is considered to be a relatively "clean" fishery with little incidental harvest of non-target species."(Burrage et al. 1997).*[45] This report has a good review of the various menhaden bycatch studies.

4. Dr. Larry McKinney of the TPWD made the following statement to the members of the Texas Parks and Wildlife Commission in August 2007: "So the decision is

what's the most valuable use of menhaden? Is it to support our recreational fishermen, which it's a keystone to, or otherwise? So contemplating this as a policy action, to step forward now and say that we want to make that decision now to reserve this fishery to support recreational fishing where the economic returns are greater, that's something that we want to put on the table for our anglers to talk about, and in front of you all."

Is there any science to support an argument that harvest of menhaden, or any other so-called "forage fish," represents a trade-off between that commercial fishery and recreational fisheries for gamefish that prey on them? If so, what is the factor? (E.g,, what amount of revenue is lost to recreational fishing communities per ton of menhaden caught?.)

The science of valuing ecosystem components is at the discussion stage. There are no definitive assessments and no published attempts to value menhaden's "ecosystem services". While not at the ecosystem services level, it is worthwhile to note two menhaden economics studies at the regional impact level. Dr. James Kirkley of VIMS is a leader in the field of both types of valuations and also studies menhaden economics. Dr. Kirkley is leading a study to "Estimate and assess social and economic importance and value of menhaden to Chesapeake Bay stakeholders and region."[46] An earlier study financed by the recreational fishing industry failed to treat recreational and commercial fishing equally and is fraught with other analytical problems. Kirkley has pointed out its shortcomings and with respect to part of the valuation of ecosystem services, he says, "Their work offers no conclusions about how economic activity generated by anglers targeting these species might change as the abundance, availability, and age class structure of menhaden changed".[47] Considering that there are no community level studies, it is understandable that valuations that would also consider interspecies and environmental relationships do not exist.

The fact that there are no hard numbers does not mean we cannot use economic theory to better understand the system.

In economic analysis, we normally would look at a situation from a micro (a firm or entity) and/or from a macro (the economy) perspective. From a micro view, we can look at an individual fish in terms of its value. We know from the GSMFC that menhaden are food-limited and from field and laboratory research (Durbin and Durbin 1998) that menhaden schools can clear the water of food as they pass through. If one fish of a thousand is removed from a school, the food it would have eaten is then used by some other fish in the school. The future energy is not lost and flows to other fish in the school. Fewer fish die of starvation or weakness (in a realm of predators), and each becomes a little bigger with somewhat more food value to those who eat it. Thus, one fish, or some reasonable number of fish, has little or no economic value to the ecology after removal because its nutritional worth is assumed by others and future food or harvest is undiminished. Its instantaneous value to the fisher or a predator is its only value. Since GSMFC (2007) shows us that there are alternative food sources for predators, including other menhaden, the predator populations will be unaffected, as will be those who harvest them. The primary value of these fish above the point where food starts to become a constraint on productivity lies in their value to the human users.

The concept above is taken from the science of population dynamics, which shows us that maximum productivity in virtually any population occurs at a level substantially below the carrying capacity of the ecosystem. When populations are reduced, fish, just as mammals, reach maturity faster, have more and healthier young, are resistant to disease, are better able to defend themselves, and, very importantly in warm estuaries, are less able to transmit crowding-dependent diseases to each other. Whether deer in a residential community or a menhaden in a Texas bay, each population will quickly out eat its food supply as soon as its predators are reduced. We do not want to re-introduce wolves into our back yards nor do we wish to stop our commercial and recreational fisheries. We are left with little choice but to thin the stocks ourselves. It is particularly important with menhaden because their food is not just our ornamental plants, but it is the food of the young fish everyone cares about, and the fish themselves, as well as the small animals that eat the algae turning our waters green.

Thus, there is more value in removing a fish, or even 20% of the population as is presently done, because the overall biomass of menhaden (forage base) will stay about the same, while some of the competitive impact (but not much of the predatory impact) will be reduced. In fact, maximum production in fish stocks generally occurs when the population is markedly lower (up to half) than its virgin level or carrying capacity (Caddy and Csirke 1983).[48] Atlantic herring (a menhaden cousin) have been found to be 30-50% reduced in weight-at-age due to food constraints when at high population levels (Cardinale and Arrhenius 2000).[49]. Since menhaden have a diet that is less benign than generally believed, it is out of balance with its ecosystem when its population approaches carrying capacity levels. With reduced natural predators, the menhaden population will expand beyond its natural level, making it difficult for any species with reduced spawning ability (such as from overfishing, disease, or reduced habitat) to overcome predation and competition by menhaden and other filter feeders.

Recreational and commercial fishing are both very important contributors to coastal economies. The true value is difficult to obtain because statistics are usually imperfect and can be manipulated to underwrite virtually any policy objective. Clearly, menhaden are an important food resource for coastal birds, predatory fish and marine mammals. They are also an important input for our meat, manufacturing, and health industries. Both sectors provide economic, food, aesthetic, and health benefits but the important aspects are seldom treated similarly during comparisons.

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