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Dr. Slack,

I am writing to provide comments on the draft SAGES report presented in Seguin, Texas on April 29, 2009. Your study has provided valuable new information on some topics including wolfberry production and blue crab recruitment. However, I disagree with your conclusions about the relationship of inflows, blue crabs and whooping cranes. I find the SAGES study very misleading mainly because it contains false assumptions and does not properly account for existing knowledge in the scientific literature.

My comments are presented numerically, with supporting material in 4 appendices.

1. **The SAGES study results are contrary to what I have observed during 28 years at Aransas monitoring the whooping crane population.**

Data collected at Aransas National Wildlife refuge indicates a relationship between marsh salinities, blue crab populations, and whooping crane survival. In general, when inflows are high and bay and marsh salinities are low, blue crab populations do well, and whooping crane mortality is low. With reduced inflows and high marsh and bay salinities, crabs do poorly and whooping crane mortality rises dramatically. This higher mortality makes sense since blue crabs make up 80-90% of the whooping crane diet when crabs are available (Chavez-Ramirez 1996) and are the predominate food of whooping cranes (Stevenson and Griffiths 1946, Allen 1952, Blankinship 1976, Hunt and Slack 1987, Nelson 1995, Chavez-Ramirez 1996).

Observations from weekly aerial survey whooping crane distribution data, monthly surveys initiated in the 1990s of blue crab, wolfberries and salinities in the bays and marshes, as well as observations of experienced personnel, were compiled to characterize what habitats the cranes were using throughout the winter which relates to general patterns of food consumption. Variables monitored were characterized in comparison with other winters as high, medium or low for either the entire winter or portions of the winter. Whooping crane mortality was detected on weekly aerial census flights (Stehn and Taylor 2008).

Data for the past 21 winters separated into winters of high (> 1.5%) whooping crane flock mortality (Table 1), and low (<1.5%) whooping crane flock mortality is shown below (Table 2). Annual flock mortality is provided in Appendix 1.

In the last 21 winters, whooping crane mortality was high (> 1.5%) in 7 of those winters. For the 7 winters with the highest whooping crane mortality; all but one (winter of 1993) had high salinities for much of the winter. For the winters with crab populations monitored, all (n=5) had low blue crab populations. Five of 6 had notably high levels of upland use. Wolfberry production ranged from abundant to low, and the amount of clamming and acorn levels differed depending on the winter. When in a winter of high salinities and low blue crab populations, this long-term data anticipates that whooping crane mortality will be high. In the winter of 2008 with high salinities, blue crabs and wolfberries, the two major foods of whooping cranes, were both extremely low and 23 whooping cranes died (8.5% of the flock), the highest winter mortality recorded in the past 21 years.

Table 1. Habitat conditions associated with high mortality winters (>1.5%) for whooping cranes at Aransas, 1988-2008.

Winter	% Mortality	Salinities	Crane Use of Freshwater	Blue Crab	Wolf-Berry	Use of Clams	Acorns	Upland Use
1988	4.3%	High	High	-[1]	-	-	High	High
1989	3.4%	High	High	Scarce	-	-	High	High
1990	7.8%	High thru Jan. Lower Feb-Apr.	High thru Jan. Lower Feb-Apr.	-	-	-	High	High
1993	4.9%	High, 14-26 ppt[2], though usually<23ppt in connected ponds	Only seen in December	Low, small crabs re-populated marsh starting in late Feb.	Abundant	Little observed	low	Low, but moderate use following burns
2000	3.3%	High thru Dec. Low Jan.-April.	High thru Dec. Low after Dec.	Scarce, especially in mid-winter	Moderate, but still notable part of diet	Use noted	scarce	High
2005	2.7%	High	Use occurred, especially 2nd half of winter	Low	High	High	scarce	Some use on burns
2008	8.5%	High	High	Low	Low	High	scarce	High, especially on M.I.

1. Blue crabs were not monitored until 1992 when Chavez-Ramirez started his study. Refuge personnel continued monitoring blue crabs after his study was completed in 1993.

2 Parts per thousand (ppt)

A typical pattern of habitat conditions present during all 7 high mortality winters was apparent as follows;

- Blue crabs were in short supply.
- Salinities were high forcing the cranes to seek out fresh water to drink except in 1993 when salinities were high but generally stayed below the threshold that forces cranes to seek out fresh water to drink.
- Considerable crane use foraging on clams and invertebrates in open bay habitat was documented, with some exceptions.
- Considerable foraging occurred on uplands.

In an average winter, blue crabs and wolfberries are readily available when the cranes return to Aransas in the fall. High tides in late September/early October have inundated the marshes and allowed crabs to disperse into connected and unconnected ponds. Starting in October, wolfberries are flowering and fruiting into December. Usually sometime in December, the cranes have consumed many of the blue crabs in the marshes, and the wolfberry crop is well past its peak and over by the end of the year. Starting in late-November, low pressure systems that reach the coast lower temperatures and bring north winds that blow the bay waters out into the Gulf. Tides are lowered dramatically. Blues crabs tend to move from the marshes into the open bays as marsh water levels and temperatures drop. Many crabs seek out deeper water which tends to be warmer than the shallow marsh waters. Whooping crane food habits shift dramatically to foraging in open bay habitat for clams and invertebrates in the substrate. During this mid-winter period, much crane upland use may occur, especially immediately after prescribed burns that provide animal matter killed in the fire (snakes and insects) or makes acorns on the mainland readily available when the mast crop is sufficient. Upland use also occurs on barrier islands following prescribed burns, as well as on disturbed soils mostly rooted up by feral hogs with the cranes foraging on tubers including nutsedges and ground cherries. In late winter, as temperatures and tide levels increase, blue crabs start moving back into the marshes, and whooping cranes go back to feeding on crabs. Fiddler crabs may become a larger part of the diet as spring days become warmer and the fiddler crabs are higher in their burrows due to the higher marsh water levels.

A correlation has been noted between the winters of high whooping crane mortality (1988, 1989, 1990, 1993, 2001, 2005, 2008) and low river flows on the Guadalupe below the level of 1.3 million acre-feet recommended by TPWD required for a health bay/estuary system (R. Sass, Professor of Natural Sciences, Emeritus, Rice University, unpublished data). Dr. Sass came to the following conclusions:

"*1. A high (whooping crane) mortality rate is always accompanied by a low river flow and the resulting high salinity.*

2. A whooping crane response to low river flow (high salinity) is one of excess stress. This condition does not necessarily lead to death but may be manifested as lack of sufficient bodily fat and protein that will be exhibited during the spring migration and subsequent poor reproductive behavior...

3. Complete and accurate data on environmental stress that is manifested by poor migratory and reproductive behavior is hard to generate but may well be a major part of the story on salinity-diet relationships…"

For the 14 winters with low whooping crane mortality < 1.5%, all had high blue crab populations except during mid-winter periods. Blue crab populations always decline in late fall and into the winter due to consumption by whooping cranes, the draining of the marshes from low pressure systems that bring northerly winds that lower marsh water levels dramatically as bay waters are blown out into the Gulf, and crabs moving to deeper water to find warmer and deeper water. Thus, blue crab levels are always lower during mid-winter. SAGES should have focused on crab movements in and out of the marshes since without regular replenishment of blue crabs in the marsh from crab movements, the cranes will consume most of their available food supply.

Table 2. Habitat conditions associated with low mortality winters (<1.5%) for whooping cranes at Aransas, 1988-2008.

Winter	% Mortality	Salinities	Crane Use of Freshwater	Blue Crab[1]	Wolf-Berry	Use of Clams	Acorns	Upland Use
1991	0.8%	Low	Low	-	very high	Low	High	high
1992	0.0%	Moderate (10-20 ppt[2])	Low	High	High	Low	High	high
1994	0.0%	High thru mid-Dec., then lower	Medium	High into Jan., then low	High	Medium	Low	Low
1995	0.6%	high	High	High in fall, low in Jan-Feb, medium in spring	Abundant	Moderate	Moderate	high
1996	0.0%	High until mid-March rains	High thru mid-Jan., then moderate	High in fall, moderate mid-winter	High	Low	High	Moderate
Winter	% Mortality	Salinities	Use of freshwater	Blue crab	Wolfberry	Use of clams	Acorns	Uplands use
1997	0.5%	Low	None	High in fall, then moderate	High	Moderate use mid-Dec to mid-Feb.	High	Some use on burns and hog rootings
1998	0.0%	Low	Very low	High except in mid-winter	Moderate+	Low	moderate	Moderate
1999	0.5%	High	High	High in fall, but then scarce	Moderate to high	High	High	High
2001	1.1%	Moderate	Low	High in fall, then medium	High	High	moderate	Moderate
2002	0.5%	Moderate	None	High	High	Low *	High	Low
2003	0.5%	Moderate	Moderate	High in fall, low Jan-Feb. high mid-March	High	Low	High	Low, moderate on burns

2004	0.9%	Low	Low	High in fall and spring, low mid-winter	High	Low to moderate	Low	Low except moderate on burns
2006	0.0%	High first half of winter, then dropping below 23 ppt	High through Dec., low after mid-Feb.	High in fall, then moderate	High	moderate	High	Moderate
2007	0.0%	Low first half of winter, increase to 20 ppt by spring	Moderate	High except mid-winter	High	Moderate in mid-winter but very high on March 5 census	-	Moderate on burns, high on M.I. uplands/burns

[1] Blue crabs were not monitored until 1992 when Chavez-Ramirez started his study. Refuge personnel continued monitoring blue crabs after his study was completed in 1993.

[2] Parts per thousand (ppt)

The correlation between increased whooping crane mortality occurring when blue crab populations in the marshes are low invalidates the SAGES conclusion "that food is not an issue for whooping cranes except in the most extreme conditions." Without blue crabs and wolfberries available, cranes are forced to eat other foods. These other foods are not as good at meeting the energy and nutritional needs of wintering whooping cranes (Nelson 1995). If other foods such as clams, insects, tubers and snails provided everything the whooping cranes needed, then high levels of mortality would occur in both high and low blue crab winters. My observations support the observations of other researchers that the key to whooping crane well-being during winter are adequate blue crab population.

SAGES should look at flock dynamics and habitat conditions at Aransas over more than 2 decades and compare them with inflow data including possible time lag affects.

2. The SAGES study results fail to account for the conditions observed during the 2008 winter at Aransas.

The conclusions of the SAGES study fails to account for the record level of whooping crane mortality during the 2008 winter (8.5%). Neither of the crane winters in which the SAGES project collected blue crab data were anything near as bad for the cranes compared with 2008.

CHARACTERIZATION OF THE 2008 WINTER AT ARANSAS

The fall of 2008 had the worst crop of wolfberries I had ever observed at Aransas in the past 28 years. Data from a transect walked on November 10th, 2008 found only 12 wolfberry fruits and no wolfberry flowers on one transect about 150 meters long that we have been monitoring for years. The previous November, on the same transect, we had counted 416 flowers and 60 fruits. The SAGES study concludes that wolfberry production is negatively affected by high summer salinities, which fits in this case since the area experienced an extreme drought and salinities were high. The cranes did not get much benefit from the wolfberry crop in the fall of 2008. Moderate numbers of blue crabs were available when the cranes first arrived, but numbers quickly tapered after the cranes started feeding on the crabs. Commercial whooping crane boat captain Tommy Moore emailed me on November 11th:

> "There are no wolfberries. It is like that all over the marsh. I have been watching the cranes' feeding habits and only every once in a while do I see one pluck a wolfberry from the vegetation. They are mostly digging for fiddler crabs is my guess. I have not seen a blue crab consumed this year (on 4 trips). We did see a snake eaten on Ayres Island. Looks like a tough year."

A food survey done by refuge personnel on December 1, 2008 found only one blue crab and 2 wolfberries. Salinities were measured at 30 parts per thousand (ppt) at the refuge boat ramp and 43 in unconnected ponds at the refuge boat ramp marsh. The same day, an emaciated subadult crane unable to stand was picked up near the refuge boat ramp. The next blue crab survey on December 30th found zero blue crabs, and that finding was replicated on monthly surveys the remainder of the winter.

On January 7, 2009, I spoke with Karen Meador of Texas Parks and Wildlife Department (TPWD), Rockport. She stated that ongoing bay sampling was finding low numbers of blue crabs, but not at alarmingly low levels. However, commercial blue crab harvest was very low and crabbing pressure was down. Salinities were very high, measured at 30 ppt in Copano Bay.

From my aerial census flight report on January 8, 2009 I wrote …"Although the Tour Boat Captains occasionally see cranes catching a crab, many of the birds have switched to eating razor clams in open bay habitat. The increased amount of crane use in open bay habitat on the flight (n=79 out of 228) is indicative of the food stress the population is facing."

Monthly crab surveys done the rest of the winter and spring also failed to find any blue crabs. Although the whooping crane tour boat captains would occasionally find a whooping crane eating a large blue crab, the overall consumption of blue crabs was way below the norm and extreme low. The very low availability of blue crabs and wolfberries during the 2008 winter for the cranes was correlated with record high mortality. Seventeen juveniles and 6 white-plumaged birds died, a record total of 23 cranes (8.5% of the flock).

Information on specific causes of mortality was obtained on the two intact carcasses recovered. The first bird captured live died as it was being transported to medical help. A necropsy done by the National Wildlife Health Lab in Madison, Wisconsin showed the bird was extremely emaciated and only found an injured knee that could have contributed to the bird's death. A white-plumaged bird had been seen limping with restricted foraging ability in Saskatchewan in the 2008 fall migration. It is possible that was the same bird as the one picked up live at Aransas and had been unable to get enough food over an extended period of time. The low levels of food availability at Aransas were presumably too much for the bird and it continued to weaken until it could no longer stand.

The second whooping crane carcass recovered was a juvenile that was observed being aggressively picked on by a territorial male on January 13, 2009. Since the juvenile's parents flew off during the territorial encounter, I postulate that the juvenile was too weak to fly off. It was predated with 48 hours of its encounter with the territorial male. A strain of infectious bursal disease (IBD) was isolated from the carcass, the first time IBD has ever been isolated from a crane. Very little work has been done on IBD in cranes, so the disease presumably may have been epizootically affecting whooping cranes at Aransas over a long period of time. IBD has been documented in whooping cranes and other birds including wild turkeys in Florida (Candelora et al. 2008), and may be present at captive whooping crane breeding facilities. One of the symptoms of IBD is emaciation, even when the bird is receiving adequate food supplies. However, the particular strain of IBD isolated from the Aransas whooping crane is different from other known strains, so how it affected the crane is speculative.

IBD mainly affects juvenile cranes since the virus grows in the bursa, an out pocket of the cloaca that is not present in white-plumaged cranes. Thus, the 7 mortalities of white-plumaged cranes at Aransas in the 2008 winter probably hadhad anything to do with IBD. The loss of even 7 whooping cranes ranks 2008 as a high mortality winter.

Field observations in the 2008 winter showed a correlation between low blue crab populations and high whooping crane mortality. Food supply can often be a limiting factor for wildlife populations. It makes sense that whooping cranes are going to do better when food supplies are adequate versus when food supplies are limited. SAGES seems to be denying this by suggesting food supplies are more than sufficient in crane territories. The fact that whooping crane territories appear to be approaching minimum sizes (Stehn and Prieto, In Review) suggests that territorial whooping cranes must defend a large enough area to maintain an adequate food supply for the territorial pair and their young of the year. With territories reaching minimum sizes and not observed to be getting smaller suggests that food is becoming limiting. If the wintering grounds were chock full of food for the cranes annually and that food was not a limiting factor in all but the most extreme winters, as stated by the SAGES report, I would expect to be seeing whooping crane territories continuing to get smaller and smaller until food becomes a limiting resource. Since territories are at or close to minimum sizes already, this provides evidence that food may be limiting. This is a far different conclusion than that described in the SAGES report. The inverse relationship between blue crab population size and whooping crane mortality shown by Pugesek et al. (2008) also provides evidence that food is a limiting factor (see below). I therefore do not see the relevance of the analysis done on p. 55 that hypothetically “shrinks” the size of whooping crane territories since there is evidence that this is not happening at Aransas as the cranes continue to slowly expand their range rather than increase the density of wintering cranes.

3. **SAGES study results are contrary to the conclusions of Pugesek et al. (2008). The SAGES report should attempt to explain this difference.**

For an eight-year period starting in 1993, intensive surveys were done by Pugesek et al. (2008) to estimate the number of blue crabs available to whooping cranes. The winters of 1993 and 2000 were poor crab years; the remaining six winters all had adequate numbers of blue crabs present. During the two winters with poor crab numbers, seven and six whooping cranes died respectively. In all six other winters, either zero or one whooping crane died. This showed a statistically significant inverse correlation between blue crab abundance and adult whooping crane mortality (Pugesek et al. 2008).

The SAGES report needs to explain why findings from the SAGES study which collected blue crab data only in 2 winters differs from the findings of the 8-year data set of Pugesek et al. (2008). It is a critical oversight not to have even mentioned the Pugesek et al. (2008) manuscript anywhere in the SAGES report even though I had emailed the manuscript to SAGES team members. This oversight seems to be characteristic of the SAGES study in failing to thoroughly review existing literature on many topics of the study including the relationship between inflows and blue crabs.

4. **Study results from SAGES about whooping crane foods seem in direct conflict with previous crane research. The discussion section found in scientific manuscripts that should attempt to relate current findings with previous research is missing in the SAGES report. Please discuss what field data you collected to come to different conclusions from previous studies.**

Numerous studies have found blue crabs to be an important food resource for wintering whooping cranes (Allen 1952, Stevenson and Griffiths 1946, Blankinship 1976, Hunt and Slack 1987, Nelson (1995), Chavez-Ramirez 1996). When blue crabs are scarce, the whooping crane population is under stress and does poorly (Nelson 1995, Chavez-Ramirez 1996, Pugesek et al. 2008). Allen (1952) found the diet in fecal samples to be 85% blue crab. Chavez-Ramirez (1996) found that when available, blue crabs can make up 80-90% of the diet of whooping cranes. An individual crane can consume up to 80 crabs per day. Blue crabs appear to be the most important source of energy for wintering whooping cranes contributing between 62% and 97% of overall energetic intake during different months (Chavez-Ramirez 1996). He did note that blue crabs may become a limited resource in some years. In October through December 1993, the second winter of his study, a lack of blue crabs which was only partially offset with an increase in wolfberry consumption, affected the potential for energy storage throughout the wintering period resulting in negative energy balances through the first half of the 1993-94 winter (Chavez-Ramirez 1996). Studies by Nelson (1995) of whooping crane food items (crabs, clams, wolfberry, acorns) showed that blue crabs were the highest in protein and nutrition for the whooping cranes. When crabs are not available, whooping cranes will switch to other foods, but because of the poor nutritive value of these alternate foods, whooping cranes may actually burn up fat reserves and have a net loss of energy for periods of the winter (Chavez-Ramirez 1996). Nelson (1996) noted an apparent instance of food shortage contributing to higher whooping crane mortality from late fall of 1993 to fall of 1994. This negative energy balance may also have manifested itself in greater than normal over-winter mortality and reduced nesting effort in the subsequent nesting season where 37% of the adult pairs failed to nest (B. Johns, Canadian Wildlife Service, unpublished data). This was unusual since normally just about all pairs attempt to nest annually. In addition, production was reduced from the pairs that did nest (B. Johns, Canadian Wildlife Service, personal communication). This was believed to have resulted from their reduced fat reserves that had not built up sufficiently during the previous winter.

A statistically significant inverse correlation between blue crab numbers and increased adult whooping crane mortality has been documented (Pugesek et al., 2008). It is well known that whooping cranes will eat other food items when blue crabs are not available, but energy content studies done by Nelson (1996) showed that blue crabs were higher in protein and lipids than other foods sampled. During most mid-winter periods when cranes switch their diet to eat clams, Nelson (1996) found that *Rangia cuneata* was a suboptimal energy and nutrient resource since it was low in gross energy and protein compared with the other crane foods studied.

From observations made over many winters, I can estimate food availability throughout the winter based on distribution of the cranes observed on aerial census flights as described by Chavez-Ramirez (1996). For example, severe food shortages in the 2008 winter changed crane distribution dramatically with greatly increased amounts of upland use observed, cranes utilizing game feeders, and increased clamming in open bays. These levels of use are not observed when blue crabs and/or wolfberry are available to the cranes, an indication that these other foods are suboptimal foods.

The first winter (2004) of the Sages study that did intensive blue crab sampling was a low whooping crane mortality winter (0.9% of the flock). The second and final winter (2005) of the SAGES study that did intensive blue crab sampling was a high mortality winter with 6 whooping cranes dying out of a flock of 220 (2.7%). There were noticeably more crabs present in 2004 compared to 2005. Walking surveys (n=6) found an average of 48 crabs/hour in 2004 and 38 crabs/hour in 2005 (T. Stehn, USFWS, unpublished data). Crab surveys done on 3 consecutive days in March following the methodology of Pugesek et al. (2008) who found that the March surveys were the best reflection of overall winter crab levels, recorded 3.22 crabs/100 meters in 2004 and 1.43 crabs/100 meters in 2005. Crabs were notably scarce in the second half of the 2005 winter and the crane population was under stress, a notable difference from the second half of the 2004 winter. The SAGES report fails to account for this difference and SAGES researches did not detect the way the whooping cranes were impacted differently in these two winters. Instead, the SAGES report on page *vi* states "None of the study results indicated that habitat conditions at Blackjack Peninsula are marginal for crane survival and well-being".

5. The SAGES study fails to analyze existing data sets.

The SAGES study collected two years of field data on crane foods. Existing multi-year data sets should be analyzed as follows:

a) Analyze inflow data and bay salinities in relation to whooping crane mortality.
b) Analyze inflow data in comparison with TPWD fisheries blue crab sampling data from Aransas and San Antonio bays.
c) Analyze inflow data in comparison with commercial crab harvest data.

6. The SAGES study model assumes that blue crab numbers are directly correlated with rising salinities up to 30 ppt. This assumption is based on laboratory studies and is false!

With the blue crab well documented as the primary food of whooping cranes, one of the most crucial objectives of the SAGES study was to determine how blue crab numbers in the crane marshes were related to salinities. Page 42 of the SAGES report states; "*In the model we selected, crab density was positively correlated with salinity, which agrees with Cadman and Weinstein 1988*". On p. *vi*, the SAGES report states; "Consistent with prior studies, blue crab abundance tends to increase with bay salinity." Instead of objectively leaving the relationship between blue crabs and salinities as an unknown and collecting all possible sources of data to shed light on this relationship, the SAGES study **assumed** that more crabs were present when salinities were higher. This assumption was based on laboratory studies (Cadman and Weinstein 1988) and does not fit field conditions observed in the winter range of the whooping crane nor data collected by Texas Parks and Wildlife Department (Longley 1994, M. Fisher, TPWD, personal communication). **This assumption made by SAGES is false and pervades and invalidates the entire SAGES model and study.** Neither Longley (1994) or Mark Fisher (unpublished data) found that blue crabs were more abundant in higher salinities as assumed by the SAGES study. Texas Water Development Board (TWDB)/TPWD model results for the Guadalupe Estuary predicted a harvest of 255,500 pounds under MinQ and 379,900 pounds under the higher inflows and lower salinities of MaxH (Longley et al. 1994). The SAGES assumption did not hold true for all the drought winters I have observed when blue crabs were scarce. Field sampling shows that blue crab populations usually crash in periods of drought. Examples of this were the winters of 1989, 1993, 2000, 2005 and 2008. The assumption needs to be changed in the SAGES model. I expect this would drastically change the conclusions of the SAGES study.

On October 28, 2004 I talked with Dennis Pridgen, TPWD fisheries biologist in Rockport, Texas. He noted how zoeal and megalopal stages of blue crabs need high salinities (> 25 ppt) for high recruitment with much of the spawning occurring in the Gulf of Mexico. After successful development of megalopae, survival of early crab stages is complicated, based on synergistic effects of salinity, temperature, pollutants, predation, disease, habitat and food availability. The first blue crab stage (2 ½ mm) and subsequent stages show the best abundance and growth when salinities are intermediate (10-20 ppt) (D. Pridgen, TPWD, personal communication). He also stated that "*Inflows between April and July will influence crab survival positively. If inflows are high during this period, the blue crab population will do well. Thus, April to July inflows are very important to the whooping crane food base.*" Notes I took from the conversation with Mr. Pridgen that were proof-read and edited by him for accuracy are provided as Appendix 3. Tom Wagner (TPWD Fisheries biologist, Rockport) in an email written to me January 5, 2005 noted "increased spring salinities will reduce juvenile blue crab growth, thus reducing energy available to cranes".

Scientific research in other estuarine systems in general demonstrates a positive relationship between inflows and blue crab populations. The SAGES study needs to exhaustively research the literature on this relationship, account for this knowledge in their report, and relate it to their field data collected on blue crabs in 2005 and 2006. Guillory et al. (2000) stated that "juvenile blue crabs are most abundant in low to intermediate salinities characteristic of middle and upper estuarine waters". Rounsefell (1964) found "low salinity marsh is an important nursery habitat for juvenile blue crabs and increased salinities may adversely impact the species" (as cited in Guillory et al. 2000). Guillory et al. (2000) found "*a blue crab recruitment index as correlated with lagged summer/early fall Mississippi River discharge (positively) and salinity (negatively), whereas commercial harvests were significantly correlated with unlagged Mississippi River discharge (positively) and salinity (negatively). They also state that the effects of discharge and salinity on blue crab recruitment and abundance were probably manifested indirectly through biotic mechanisms such as predation*".

Longley (1994) analyzing a long-term data set reported an inverse relationship between salinities and blue crab numbers. This totally disagrees with the SAGES assumption in the model that blue crabs prefer higher salinities, an assumption that is not based on field data collected by SAGES. TPWD data shows that more blue crabs are generally found not in the highest salinity areas in the estuary but in more moderate salinity areas of 5-15 ppt (Longley 1994).

Others have written about the implications of a causal relationship between inflows and high blue crab numbers. (Kretzschamer 1990) calculated that by the year 2040, due to anticipated diversions, a predicted decrease of 555,000 acre-feet of gauged inflows in an average year into the crane's winter range was projected to cause an 8% decline in blue crab populations (Texas Department of Water Resources 1980), but could have a much larger impact in drought years (N. Johns 1994).

Texas Water Development Board data indicate natural droughts already threaten the Guadalupe ecosystem. Without sufficient inflows, wildlife resources, including fish, crabs, and shrimp, all decline. The 1.15 million acre-feet figure derived by TPWD is often quoted as an amount needed to maximize harvest of 9 marine species of commercial interest in the bays and estuaries. In the case of blue crabs, more than 1.15 million acre-feet is needed to produce high blue crab populations. TPWD data clearly show that increased water inflows result in higher blue crab numbers (Mendoza 2001). Crab survival of all life stages increases when salinities are generally below 20 ppt. Blue crabs were found to be more abundant in the Guadalupe Estuary in salinities averaging between 10-25 ppt. A simple inverse relationship exists between blue crab catch rates and mean salinity within an estuary (Longley 1994). Peak crab counts in the bays occur following periods of flooding. In San Antonio Bay, the 3 highest blue crab harvest years were all having inflows greater than 3 million acre-feet annually. Thus, to maximize blue crabs for whooping cranes to eat, managers should maximize freshwater inflows on the Guadalupe River. Providing for guaranteed minimum inflows to the bay is essential.

7. The SAGES study needs to comment on how marsh salinity levels could impact growth of sea grasses and algae in marsh ponds.

Blue crab survival in the marshes is dependent on habitat in which they can hide from predators. Vegetated habitats are favored by blue crab over un-vegetated habitats (Rozas and Minello 1998). Many of the ponds at Aransas seem to have little aquatic vegetation growing in them except for algae. I have observed increased growth of seagrasses and algae during low salinity years in the ponds. Thus, reduced inflows could increase marsh salinities, reduce growth of seagrasses, and thus limit blue crab populations.

8. The SAGES study needs to relate reduced inflows with the increased time periods that salinities in unconnected marsh ponds in the crane winter range would exceed 30 ppt.

Long-term crab sampling data compiled in May, 2009 shows blue crab bag seine catch per unit effort in San Antonio and Aransas bays per salinity zone showed no differences for salinities below 30 ppt, but showed declining blue crab populations in salinities greater than 30 ppt (Mark Fisher, Texas Parks and Wildlife Department, unpublished data). If one assumes this to also hold true in the salt marshes, I have observed multiple drought years at Aransas when marsh salinities in unconnected ponds greatly exceed 30 ppt. Crabs presumably are avoiding these hypersaline ponds, thus greatly lowering the carrying capacity of the salt marshes to sustain blue crab populations. I recommend that the SAGES study look at how often reduced inflows would increase marsh salinities in unconnected ponds above 30 ppt and how that would lower the blue crab carrying capacity of the marsh.

9. The SAGES study misuses data on the smallest age classes of blue crabs.

Whooping cranes generally do not eat the smallest size classes of blue crabs (<30 mm). This needs to be factored in to the energetic model. Whooping cranes do not eat blue crabs 11 mm or smaller. I would also estimate that blue crabs 20 mm or smaller probably don't make up a significant part of the whooping crane diet either. Whooping cranes are normally seen eating crabs something at least as large as a fiddler crab, or blue crabs 30 mm in size or greater. Crab densities used in the SAGES model (crabs per square meter) should exclude all blue crabs <30 mm since they are basically not used by whooping cranes. Although the smallest sized blue crabs may presumably be a good indication of subsequent recruitment into the larger size classes, many other bird species prey on very small crabs, and many of these small blue crabs will die at Aransas during summer when much of the marsh at Aransas dries up.

With blue crabs > 30 mm the main food of the whooping crane, it is essential that the SAGES model be able to successfully reflect many aspects of blue crab biology. Especially important would be how blue crab availability for whooping cranes changes during the course of the winter due to many factors including consumption of crabs by whooping cranes and other wildlife species, movements of blue crabs in and out of the marshes, and differential availability of blue crabs during periods of colder temperatures as noted by Chavez (1996). Yet on p. 108, the Sages report states: "Model selection procedures used to explore the density of blue crabs > 30 mm in size often resulted in non-convergence or excessively large dispersion estimates".

Danielle Greer also failed to sample crabs in some key "bayou" habitat at Aransas. These bayous consist of very narrow channels that interconnect marsh ponds. On one blue crab survey in particular, I remember walking the marsh for over an hour and the only place I finally found crabs was in a bayou too narrow to be sampled using Danielle's methods.

10. The important role of sediments, nutrients and organic matter brought by inflows to the Guadalupe Estuary is not accounted for in the SAGES study that seems focused on a salinity-based model only.

Blue crabs and bay and marsh productivity are impacted by sediments, nutrients, and organic matter that are brought to the estuary by inflows (Longley 1994). For SAGES to be making public statements that inflows can be reduced 90% without hurting the food base of the whooping crane based on their salinity-based model that does not properly account for the importance of sediments, nutrients, and organic matter in maintenance of bay productivity is very misleading.

11. The SAGES study fails to show the temporal aspects of whooping crane food availability.

Page 70 of the SAGES report states:

> "*The food supply for cranes appears to be more than adequate to meet their energy needs during the time period simulated. None of the study results indicated that habitat conditions at Blackjack Peninsula are marginal for crane survival and well-being. Simulation results for the 11-year period of 1997-2007 found that the metabolic energy present in wolfberry fruit and blue crabs together and in blue crabs alone, always exceeded the estimated daily energy requirements of four whooping cranes in each of the three crane territories, except under extreme marsh environment circumstances.*"

The SAGES study does not account for seasonal periods of stress for the whooping crane that occur nearly every winter. Chavez-Ramirez (1996) found major stretches of the 1993 winter when cranes used up existing energy reserves due to inadequate availability of quality foods. With blue crabs and wolfberries well documented as the preferred foods of the species, both of these items are normally in short supply in January and February. The cranes switch to foraging on clams and other benthic invertebrates. Clams and invertebrates had been present earlier in the winter but were not selected by the cranes. Therefore, one assumes that they do not "prefer" those foods. Nelson (1995) found these foods to be lower in caloric value and protein compared to blue crabs. Thus, the SAGES calculations measuring total crane food supply are meaningless when key foods are not available to the cranes for significant stretches of most winters.

On p. 147-148, the author Danielle Greer noted the change in food habits from wolfberry fruits and blue crabs to razor clams in mid-winter "*when overall food abundance was presumably low*". She noted during the second half of her final field season that cranes were not able to find blue crabs and switched their food habits to clams and insects. However, she failed to recognize how atypical this was compared to winters when whooping crane foods are sufficient and failed to correlate the stressful conditions with the death of 6 whooping cranes during her second season of field sampling.

12. The SAGES study concludes erroneously that a reduction in wolfberry production will not harm whooping cranes, with SAGES reasoning that cranes will opportunistically forage on other foods of sufficient nutrition that are present in adequate numbers in all but the most extreme winters.

The SAGES study correlates increased summer salinities in the marsh with reduced levels of wolfberry production in the fall. Wolfberries are fed on heavily by whooping cranes because of their high caloric value and because they are easily obtained. A reduction in the wolfberry crop due to decreased inflows and higher marsh salinities could negatively impact significantly the food base available for whooping cranes since wolfberries are a key component of the whooping crane diet in the fall. In 2008 with the lowest wolfberry crop I have observed in the past 21 years, the cranes had only limited numbers of wolfberries to consume. The cranes initially fed on blue crabs in the fall. As more and more crabs were consumed and crab numbers declined, the species was in trouble. Continued food stress from the extreme low levels of wolfberry and blue crab were correlated with the highest flock mortality (8.5%) documented in the last 21 years.

The SAGES model when looking at the density of wolfberry fruits needs to estimate and take into account other wildlife species including sandhill cranes and raccoons that eat large quantities of wolfberries. In fact, the only time sandhill cranes forage extensively in salt marsh is when wolfberries are available. Thus, other wildlife species may significantly lower the quantity of wolfberries available to the whooping cranes.

13. The SAGES study fails to analyze the energetic costs of cranes being forced to leave the salt marsh to drink.

Cranes are observed leaving the marsh to seek out freshwater to drink when salinities approach or exceed 20 ppt. When marsh and bay salinities exceed 23 parts per thousand (ppt), whooping cranes are forced to make daily flights to freshwater to drink (Allen 1952, Hunt 1987). Flights are presumably made several times a day, although the number of times a whooping crane must drink fresh water daily has not been quantified. I have observed cranes on San Jose Island flying 3 miles to find the nearest fresh water. These flights use up energy, reduce time available for foraging or resting, and could make the cranes more vulnerable to predation on the uplands (Tom Stehn, USFWS, Austwell, Texas, personal communication). Thus, inflows are crucial in keeping salinity levels below the threshold of 23 ppt in coastal marshes used by whooping cranes.

Inflows which mix with Gulf waters help keep salinity levels moderate. The SAGES study should assess how reduced inflows would increase the energy demands for cranes forced to seek out freshwater sources. There could presumably also be detrimental physiological aspects for whooping cranes spending the winter in highly saline environments.

14. SAGES should analyze the spike found in blue crab recruitment in relation to inflow data.

A potentially very significant spike was found by SAGES in blue crab recruitment. Blue crab larval movements into the marshes were low except during the spikes. The study should comment on what factors may have caused this spike to occur.

15. Peer review of the SAGES study was inadequate.

The technical advisory committee convened by SAGES in 2003 and 2004 was never consulted again after those early stages of the study. Thus, the SAGES study received no technical guidance during much of the study's duration and especially during the wrap-up. Not knowing who peer-reviewed the draft report, I doubt if anyone knowledgeable about whooping cranes such as a member of the Whooping Crane Recovery Team was asked to review the final report before it was released in April, 2009.

16. The report contains errors and inconsistencies, some of which are noted below.

p. 26 - Figures 2.1 and 3.1 are very different even though the text states they are identical. Figure 3.1 which is wrong shows no link between inflows and whooping crane foods.

p. 43 – Sages assumed that "wind speed was a proxy for water turbidity". In the multiple surveys done by Mike Baldwin for the Pugesek et al. (2008) study, and the multiple walking surveys I have conducted, turbidity in the narrow bayous seemed mostly related to schools of fish that would stir up the bottom sediments and cloud the water.

p. 44 – I do not understand why "the sample grid for Boat ramp did not include the large lake within that territory." The territorial Boat ramp cranes spend extensive periods every winter foraging in that large lake known as Redfish Slough.

p. 54 – The date selected by SAGES for whooping crane arrival (October 16) is actually the average date for the first whooping crane of the fall to arrive (T. Stehn, USFWS, unpublished data). The date of April 7 assumed by SAGES to be the average departure date is actually about when 50% of the flock has started the migration. Thus, there is inconsistency in what the two dates selected represent. If SAGES wants to choose a date when 50% of the cranes have arrived in the fall, I would choose approximately November 4th.

p. 108 – "*Model selection procedures used to explore the density of blue crabs > 30 mm in size often resulted in non-convergence or excessively large dispersion estimates*". With blue crabs > 30 mm the main food of the whooping crane, it is essential that the SAGES model be able to successfully reflect many aspects of blue crab biology. Especially important would be how blue crab availability for whooping cranes changes during the course of the winter due to many factors including consumption of crabs by whooping cranes and other wildlife species, movements of blue crabs in and out of the marshes, and differential availability of blue crabs during periods of colder temperatures as noted by Chavez (1996).

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Appendix 1. Mortality in the Aransas-Wood Buffalo whooping crane population 1989-2008.

High crane mortality winters at Aransas are designated by red text.

Year	Flock Size In April	Apr-Nov Mortality	Apr-Nov % Loss	Winter	Winter Mortality	Peak Winter Flock Size	% Winter Mortality	12-Month Mortality	12-Month Mortality (%)
2008	266	34[A]	12.8 [A]	2008-09	23	270	8.5% [A]	57	21.4% [A]
2007	236	9	3.8	2007-08	0	266	0%	9	3.8%
2006	214	22	10.3	2006-07	0	237	0%	22	10.3%
2005	215	25	11.6	2005-06	6	220	2.7%	31	14.4%
2004	192	10	5.2	2004-05	2	217	0.9%	12	6.3%
2003	184	15	8.2	2003-04	1	193	0.5%	16	8.7%
2002	174	5	2.9	2002-03	1	185	0.5%	6	3.4%
2001	174	13	7.5	2001-02	2	176	1.1%	15	8.6%
2000	187	16	8.6	2000-01	6	180	3.3%	22	11.8%
1999	183	11	6.0	1999-00	1	188	0.5%	12	6.6%
1998	181	16	8.8	1998-99	0	183	0%	16	8.8%
1997	160	8	5.0	1997-98	1	182	0.5%	9	5.6%
1996	157	13	8.3	1996-97	0	160	0%	13	8.3%
1995	133	3	2.3	1995-96	1	158	0.6%	4	3.0%
1994	136	11	8.1	1994-95	0	133	0%	11	8.1%
1993	136	9	6.6	1993-94	7	143	4.9%	16	11.8%
1992	131	10	7.6	1992-93	0	136	0%	10	7.6%
1991	135	11	8.1	1991-92	1	132	0.8%	12	8.9%
1990	141	9	6.4	1990-91	11	146	7.5%	20	14.2%
1989	132	7	5.3	1989-90	5	146	3.4%	12	9.1%
20-Year Average		**12.8**	**7.2 %**		**3.4 (1.3%)**	**182.6**	**1.8%**	**16.3**	**9.0%**

[A] worst loss in past 20 years.

Appendix 2. Winter notes on habitat conditions during high whooping crane flock mortality taken from unpublished file reports written annually by T. Stehn.

1962-63 winter - 4 birds lost, highest as of that date.

1988-89 winter – 6 losses out of 138 (4.3%), the highest ever recorded as of that date.

The winter was notable for the amount of crane use in upland areas and freshwater ponds. Freshwater sources, mostly dugouts, provided sufficient drinking water for the cranes. Salinities in the salt marsh exceeded 23 ppt for much of the winter. An abundant acorn crop attracted numerous cranes to feed on the uplands. On the refuge, upland use totaled 17.2% of all aerial locations. In November, interior marsh pond salinities ranged between 40 and 52 ppt. Readings in the marshes on Matagorda Island were as high as 70 ppt. Salinity measurements in early December found readings in the GIWW and adjacent bays between 32-35 ppt. These bay levels were extraordinarily high, a result of the continued drought in South Texas and the resultant lack of freshwater inflows from river systems. San Antonio Bay at the refuge picnic area was 26 ppt, the lowest level documented. After heavy rains in January, marsh salinities averaged 19 ppt and the GIWW 23 ppt. The whoopers were observed no longer making flights to fresh water to drink. The lack of rain in February and March raised salinities, measured March 28 at 25 ppt in the GIWW and bays and an average of 33 ppt in the marshes. Cranes at freshwater were first observed on March 18. Such visits continued into April.

Some upland use was documented on 12 out of 22 aerial census flights conducted during the winter. Upland use was observed on all flights between Nov. 21 and March 8. On the refuge, 17.2% of all aerial locations were on uplands. With an excellent acorn crop, the cranes found an abundant food source. The census flight on March 8 noted the lowest tides of the winter. Fifty-six of the 124 cranes were located in the bays, presumably eating clams.

1989-90 winter 5 lost out of 146 (3.4%), second highest losses to date.

The winter was notable for the amount of crane use in upland areas for foraging and freshwater ponds for drinking. Marsh salinities were recorded as high as 46 ppt. An abundant acorn crop attracted numerous cranes to feed on the uplands. Blue crabs were scarce. A news article in mid-September indicated that the 1989 commercial harvest of blue crabs was down 80% compared with the previous year. Wolfberry plants on the refuge appeared stressed in summer, 1989, many without leaves. Cranes were seen at freshwater sources throughout the winter.

There was evidence of avian tuberculosis in subadult captured in 1989 winter, and similar disease in chick that died at Aransas in 1982 winter. Increased levels of oversummering whooping cranes occurred (1 in 1988, same bird again in 1989, 1 in 1991with bird dying during the summer) that could indicate disease issues. Analysis of winter mortality between 1980 and 1990 indicated higher mortality when the marshes are salty and when the cranes utilize uplands more to feed on acorns.

1990-91 winter 11 lost out of 141 (7.8%).

In August,1990 a red tide outbreak occurred in the bay but there was no evidence of a connection with subsequent winter mortality of whooping cranes. Losses were estimated at 3 adults, 3 subadults and 5 juveniles. Most losses (8 out of 11) occurred during a bad weather stretch in late December through early January along an 8-mile stretch of the refuge. Three of the losses involved chicks that had at Aransas separated from their parents. One carcass was found, but the cause of death was not determined.

Lots of upland use and use of freshwater ponds was observed. However, little upland use occurred on Matagorda Island. Lots of acorns were present on refuge uplands. Much upland use occurred through December, but cranes also were observed catching crabs. No crab counts were done. High marsh salinities < 37 ppt were recorded. Marsh salinities were lower during Feb-April with cranes drinking directly from marsh.

1993-94 7 lost out of 143 (4.9%).

Five juveniles and 2 white-plumaged birds were lost. One juvenile had separated from its parents and showed abnormal behavior prior to predation by a bobcat.

Blue crab numbers were down notably compared with the previous winter, but small blue crabs re-populated the marsh starting in late February that the cranes quickly took advantage of. Small crabs through March provided limited food for the cranes. Commercial size blue crabs were so scarce in the spring that crab fishermen removed their traps from Sundown and Dunham bays. Acorn use was low and little clamming was documented. Marsh salinities were somewhat elevated. Wolfberry crop was abundant. Winter weather was generally mild.

This was the second winter of field work by Chavez-Ramirez and crabs were at very low levels and the cranes overall lost energy reserves during much of the winter. Food resources were considered marginal. 37% of the adult pairs failed to nest in the summer of 1994.

Salinities were higher than the previous winter and were measured between 14 and 26 ppt. Summer drought raised salinities measured in the marsh at 23-26 ppt in early October, but bays were around 15 ppt. High October tides flooded the marshes and lowered marsh salinities. Marsh salinities dropped below 19 ppt by early November and stayed below the threshold of 23 ppt throughout the winter when cranes are forced to seek out fresh water to drink. Only occasional use of cranes drinking freshwater at dugouts was documented in December. Salinities that averaged 19-21 ppt in mid-January and 18-19 ppt in February dropped to 14 ppt in March. The winter report written by T. Stehn indicated the lack of blue crabs seemed to be the most significant factor related to crane winter mortality.

2000-01 6 lost out of 180 (3.3%).

Four adults and 2 juveniles died during the winter. Also possibly one subadult died. Only 1 old carcass was found.

Red tide was documented close to crane areas at the end of October.

Food sources were considered poor during the winter. It was a bad blue crab winter for the whooping cranes. Drought the previous spring and summer with lowered inflows had perhaps lowered blue crab production. Blue crabs were never abundant and were believed to make up only a small part of the whooping crane diet. Mike Baldwin walking 3 transects each 1000 meters long found a maximum of 23 crabs over a 3-day period until mid-April when he counted between 30 and 40 crabs per day. Blue crab numbers recorded by Baldwin were the worst since 1997-98, measured at only 0.24 crabs per 100 meters. They were at low levels all winter, but really scarce in mid-winter. Almost no crabs were available in December and January, resulting in more cranes foraging on upland areas. Crabs showed a slight increase in numbers at the end of February and March as tides rose slightly, but crab counts at the end of March indicated only low numbers present. The cranes spent considerable time off of their traditional territories and moved extensively in search of food, foraging in uplands or open bays. The amount of upland use was notable. Cranes were observed in unusual locations including uplands and game feeders, including a San Jose family that came over to Lamar, presumably influenced by feeders. These alternate foods were not as nutritious as blue crab (Nelson 1995).

A most unusual occurrence of 18 whoopers spent considerable time at Willow Creek and an adjacent game feeder. This unusual location was considered related to the lack of blue crab food resources. Wolfberries were available in November and December. Although not quantified, wolfberries were less abundant than in some winters, but still made up a notable part of the whooping crane diet. Use of open bays was observed January through March. Few acorns were available due to a poor mast crop. Refuge burns received heavy use initially, but use tapered off.

For the first half of the winter, salinities were high so that crane use of fresh water sources occurred on a daily basis. March salinities in October were measured at 30-35 ppt. Refuge rainfall totals in November, January and February equaled 12.29 inches and lowered marsh salinities enough so that few cranes were observed at freshwater sources Jan-April, 2001. March salinities during mid-February crab counts averaged 22.6 ppt but ranged between 15 and 46 ppt.

Data shows that when blue crab populations are low, the cranes do not do well. Blue crabs are believed to be the key whooping crane food as shown by Chavez-Ramirez (1996). The highest mortality has occurred in the two winters when the least number of crabs were present (7 died in 1993-94 and 6 in 2000-01).In all other winters 1992-93 to 2000-01, with more blue crabs available, whooping crane mortality was either zero or one. There is a correlation between low blue crab numbers and high whooping crane mortality. This makes sense since blue crabs can make up 90% of the crane diet when available (Chavez-Ramirez 1996).

2005-06 6 lost out of 220 (2.7%).

One adult and 5 juveniles were lost, but no carcasses were recovered. Mortality was higher than average and was correlated with the shortfall of blue crabs.

Wolfberries were available in November and December with a crop rated as excellent. Quality food resources were considered good throughout the fall, but declined into winter and were scarce Jan.-April, 2006. Overall, the winter was rated as fairly poor for blue crab abundance. No spring influx of blue crabs occurred. Drought started in December, 2005 and continued into spring, 2006. Use of clams and invertebrates such as mud shrimp or blood worms in open bay habitat was observed frequently as tides remained low for extended portions of the winter. Some upland use was made of prescribed burns, but acorns were scarce.

Salinities started the winter at 16 ppt as measured on Oct. 20th. That was the lowest reading of the winter. Bay salinities in November and for the rest of the winter were above 20 ppt. Bay and marsh salinities the latter half of the winter remained above 23 ppt forcing the cranes to seek out fresh water.

2008-09 23 lost out of 270 (8.5%).

63 juveniles and 7 adults/subadults died. Three carcasses found; bad knee on an emaciated subadult found still alive at the Boat Ramp; Infectious Bursal Disease isolated from an emaciated juvenile (thought to have been flightless due to its weakened condition) predated by Dunham Bay; scatted piles of white-plumaged feathers found at Upper Pump Canal.

The wolfberry crop was very limited. Blue crabs were present initially, but soon became scarce. The cranes occasionally found blue crabs all winter, but at greatly increased search effort. Low tides drained marshes for part of winter. Considerable open bay use was observed. There was remarkably high use of game feeders, including 21 whoopers on Lamar using feeders and 2 adjacent to Highway 35 north of Holiday Beach. Salinities were high throughout the winter with the cranes making daily use of fresh water to drink.

Appendix 3. Tom Stehn's notes from talk 10-28-04 with Dennis Pridgen, TPWD fisheries biologist, Rockport.

Subject: Timing of inflows to help blue crabs.

Blue crabs show a lot of variability and adapt to a wide range of conditions. Blue crabs eggs hatch, go rapidly through 7 zoeal stages and enter megalopal stages. These early stages are all carried by currents. The megalopae then change into what are commonly known as blue crab stages. The following are general rules for blue crab life cycles.

1. After the eggs hatch, zoeae and megalopal stages of blue crabs need high salinities above 21 ppt for high recruitment. Optimal salinities for egg hatching is 23-30 ppt; optimal salinity for zoeal matemorphisis is 21-28. Survival will be lower if salinities drop below optimal, say less than 15 ppt. Thus, most female crabs move into the Gulf of Mexico to spawn where salinities are conducive to survival and growth of early life stages of crabs. In drought years, spawning could occur in highly saline marshes or bays, with conditions okay for survival of early life stages, but growth of the first blue crab life stage would be low due to the high salinities.

2. After successful development of megalopae, survival of early crab stages is complicated, based on synergistic effects of salinity, temperature, pollutants, predation, disease, habitat and food availability. The first blue crab (2 ½ mm) stage and subsequent stages shows the best abundance and growth when salinities are intermediate (10-20 ppt).

3. During warm temperatures, it takes about 4 months for crabs to grow to reach 5 cm size, an approx. minimum size that cranes can easily consume. Growth rates of blue crabs are greatly reduced during periods of colder temperatures during winter. Crab eggs that hatch during August – October will not have time to allow for enough development and growth to be available for cranes until the following spring (Feb. – April) before the cranes leave for Canada by mid-April.

4. Blue crabs available for whooping cranes in the fall are ones that were generally hatched between April and July, plus older crabs surviving from the previous year. Total crab numbers with individuals ranging in size from the first crab stage (2 1/2 mm) to large adults (7 inches) are generally highest in the fall. The crabs present in the fall provide the food base for the whooping cranes during their entire winter stay, (mid-October through mid-April), although crabs that hatch in late summer would be available in the spring. Crab numbers in the salt marsh vary throughout the winter, depending on tide levels, temperatures, and predation by whooping cranes and other critters. Crabs generally move out into the bays seeking deeper water during the colder temperature and low tide periods from December into February. They will then re-populate the marshes, starting in February or March as tides rise and temperatures increase. The crabs eaten by whooping cranes in March and April generally are survivors from the spawn during the previous April-July period when survival was high due to moderate salinities and high inflows. Note that some of the crabs growing up to breeding size during the summer were carryovers from spawning the previous fall.

5. Inflows between April to July will influence crab survival positively. If inflows are high during this period, the blue crab population will do well. Thus, April to July inflows are very important to the whooping crane food base.

6. Fall rains, including tropical systems in August through October, will generally not add to the whooping crane food supply in the coming winter. However, such fall inflows are important because they lower salinities and

create an intermediate salinity regime in the fall and the following spring, which greatly helps survival of early crab stages (as in # 2 above). If spring salinities are too high, than growth of the first blue crab stages would be low, thus reducing energy available to the cranes.

7. Crabs breed between 6-8 months of the year, with spawning determined by water temperature. In Texas there may be a peak in March and April. As crabs grow larger and reach breeding size, some crabs will be spawning all the way from spring to fall. Females that breed in the fall (late October) can hold their eggs until the next spring. Increased spawning activity is not connected with inflow pulses. A peak of spawning occurs as temperatures warm up in the spring. The length of the spawning season is determined by water temperatures remaining being warm enough, with limited spawning occurring in winter in mild winters.

8. Other bay species such as white shrimp have different life cycles. Thus, this discussion about inflows and crab populations, although in general holds true for other species, varies somewhat depending on the species. For example, August rains would tend to still help white shrimp.

Appendix 4. The relationship between inflows, crabs, salinities, and whooping cranes.

by: Tom Stehn, Whooping Crane Coordinator, U. S. Fish and Wildlife Service, March, 2008

The productivity and quality of coastal waters in winter whooping crane critical habitat at Aransas is directly dependent on freshwater inflows that start hundreds of kilometers inland from the San Antonio / Guadalupe River and flow into coastal waters (TPWD 1998). Flows from springs coming from the Edwards Aquifer are also crucial, especially in times of drought when they can make up 70% of Guadalupe River water. Thus, the ongoing reduction of freshwater inflows due to human population growth is a huge threat to the whooping crane that could lead to its extinction. The survival of one endangered species, the whooping crane, and one candidate species, the Cagle's map turtle, are directly tied to maintenance of sufficient inflows (Mendoza, 2001a).

Whooping Crane Food Needs

Sufficient inflows are required to produce the necessary food for whooping cranes to survive. Inflows that carry nutrients and sediments and maintain proper salinity gradients in the estuary are needed to produce blue crabs that are the primary food for whooping cranes. Chavez-Ramirez (1996) found that when available, blue crabs can make up 80-90% of the diet of whooping cranes. An individual crane can consume up to 80 crabs per day. Studies by Nelson (1995) of whooping crane food items (crabs, clams, wolfberry, acorns) showed that blue crabs were the highest in protein and nutrition for the whoopers. When crabs are not available, whooping cranes will switch to other foods, but because of the poor nutritive value of these alternate foods, the whoopers may actually burn up fat reserves and have a net loss of energy for periods of the winter (Chavez-Ramirez 1996).

Data collected at Aransas National Wildlife refuge indicates a relationship between freshwater inflows on the Guadalupe River, blue crab populations, and whooping crane survival. When inflows are high, blue crab populations increase due to enhanced reproduction and survival, and whooping crane mortality is low. With reduced inflows, crabs do poorly and whooping crane mortality rises dramatically. This makes sense since blue crabs make up 80-90% of the whooping crane diet. For an eight-year period starting in 1993, intensive surveys were done to roughly estimate the number of blue crabs available to whooping cranes. The winters of 1993-94 and 2000-01 were poor crab years; the remaining six winters all had adequate numbers of blue crabs present. During the two winters with poor crab numbers, seven and six whooping cranes died respectively. In all six other winters, either zero or one whooper died. There is a strong inverse correlation between blue crab abundance and adult whooping crane mortality (Pugesek et al. 2008). In addition, following the poor blue crab winter of 1993-94, 37% of the known adult pairs (17 out of 46) failed to nest following their return to Canada. This was unusual since normally just about all pairs attempt to nest annually. In addition, production was reduced from the pairs that did nest (B. Johns, CWS, personal communication). This was all believed to have resulted from their reduced fat reserves that had not built up sufficiently during the previous winter. Therefore, the very survival of the species is dependent on water management strategies that provide sufficient inflows for the bays to remain productive (Mendoza 2001b).

Whooping Crane Needs for Fresh Water

Inflows which mix with Gulf waters help keep salinity levels moderate. When marsh and bay salinities exceed 23 parts per thousand (ppt), whooping cranes are forced to make daily flights to freshwater to drink (Allen 1952, Hunt 1987). These flights use up energy, reduce time available for foraging or resting, and could make the cranes more vulnerable to predation on the uplands (Tom Stehn, USFWS, Austwell, Texas, pers. comm.). Thus, inflows are crucial in keeping salinity levels below the threshold of 23 ppt in coastal marshes used by whooping cranes.

Status of Guadalupe River flows:

Human consumption of river water in Texas is a growing resource issue as the State's population continues to expand. This is a very worrisome trend since Texas water law reserves water for people but has fewer provisions for wildlife. Leaving sufficient water in the rivers to provide bay inflows is not explicitly designated as a beneficial use of water in Texas water law. National media attention was received in spring 2001 when the Rio Grande River dried up and flows no longer reached the Gulf. This is not the only river in Texas in trouble. So many people are using water from the aquifer and the rivers in central Texas, that the downstream folks and creatures are already seeing what most Texans do not want to acknowledge; that the rivers are already over-appropriated, and absolutely no one is minding the store, when it comes to making sure any fresh water ever makes it to the bays and estuaries (Diane Wassenich, San Marcos River Authority, San Marcos, Texas, pers. comm.).

Inflows on the Guadalupe River are already insufficient and reduced over historic levels leading to increases in mean salinity and decreases in blue crabs. As water development pressures mount, freshwater inflows to the Texas bay systems are being reduced, and blue crab populations are being adversely affected. This could have an alarming impact on whooping cranes. The death of 6 whooping cranes during the 2000-01 winter emphasizes how serious an issue this is.

The Texas Water Development Board (TWDB) data indicate natural droughts already threaten the ecosystem of the Guadalupe Estuary and predict that in less than 50 years withdrawals of surface and ground waters for municipal and industrial growth will leave insufficient inflows to sustain the ecosystem (CWS AND USFWS 2007). Long before ecosystem collapse due to lack of inflows, significant adverse impacts to blue crab populations would occur (Kretzschmar 1990). By 2040, due to anticipated diversions, a predicted decrease of 555,000 acre-feet of gaged inflows (Kretzschamer 1990) in an average year into the crane's winter range is projected to cause an 8% decline in blue crab populations (Texas Department of Water Resources 1980), but could have a much larger impact in drought years (Norman Johns, National Wildlife Federation, Austin, Texas, pers. comm.). Modeling indicates that if all existing water rights were exercised during a repeat of the 1950-1956 drought, estuary inflows would be reduced by 17% to 43% below current levels and by 36% to 72% below historic levels, depending on the year (Norman Johns, National Wildlife Federation, Austin, TX, pers. comm., in Fitzhugh and Richter, 2004). Additionally, there are pending water right applications for much of the remaining unappropriated water in the Guadalupe.

Upstream reservoir construction and water diversions for agriculture and human use reduce freshwater inflows. Many existing water rights are currently only partially utilized, but greater utilization is expected over time. Water rights continue to be granted on the Guadalupe, and some sections of the river are already over-appropriated. Withdrawals of surface and groundwater for municipal and industrial growth are predicted to leave insufficient inflows to sustain the ecosystem in less than 50 years. Projections indicate the river will be significantly threatened during periods of low flow and could cease to flow into the bay if all currently authorized water-use permits are utilized (National Wildlife Federation 2004).

The San Antonio and Guadalupe Rivers that empty into whooping crane critical habitat are calculated to need 1.24 million acre-feet per year to maintain ecosystem subsistence (TPWD 1998). Yet between 1941-1976, inflows were less than that amount in 14 out of 36 years, making its status already precarious (TDWR1980). In 2002, American Rivers named the Guadalupe on their annual list of the 10 most endangered rivers in the U.S. because of the inflow issue. In a report entitled *Bays in Peril,* a "Danger" ranking was given to San Antonio Bay because drought periods were predicted to increase by 250%, and years with low freshwater pulses in the spring were calculated to increase 26% from naturalized levels (National Wildlife Federation 2004).

Texas Water Development Board data indicate natural droughts already threaten the Guadalupe ecosystem. Without sufficient inflows, wildlife resources, including fish, crabs, and shrimp, all decline. The 1.15 million acre-feet figure is often quoted as an amount needed to maximize harvest of 9 marine species of commercial interest in the bays and estuaries. In the case of blue crabs, more than 1.15 million acre-feet is needed to produce high blue crab populations. TPWD data clearly show that increased water inflows result in higher blue crab numbers (Mendoza 2001b). Crab survival of all life stages increases when salinities are generally below 20 ppt, and the very young stages in the blue crab life cycle show much better survival when salinities are moderate. Blue crabs were found to be more abundant in the Guadalupe Estuary in salinities averaging between 10-25 ppt. A simple inverse relationship exists between blue crabs catch rates and mean salinity within an estuary (Longely 1994). Peak crab counts in the bays occur following periods of flooding. In San Antonio Bay, the 3 highest blue crab harvest years were all having inflows greater than 3 million acre-feet annually. Thus, to maximize blue crabs for whooping cranes to eat, managers should maximize freshwater inflows on the Guadalupe River. Providing for guaranteed minimum inflows to the bay is essential.

Management Actions and Needs:

The San Marcos River Foundation (SMRF) in 2000 applied for a 1.15 million acre-feet water right that would remain in the rivers to provide inflows to the bay. The application was denied in 2003 but an appeal was granted, sending the application back to the Texas Council on Environmental Quality for a re-hearing. This matter remains involved in litigation with the outcome pending. The 1.15 million acre-feet is the recommended target inflow level needed to maintain the unique biological communities of the Guadalupe Estuary (TPWD 1998) and keep the bays productive (TPWD 1998, Mendoza 2001b). Unfortunately, mechanisms to guarantee these flows are not provided by Texas water law, and critics have challenged the size of the target inflows. Water developers are saying that human needs for water are too great, that there isn't enough water available to provide the water identified by the Texas Parks and Wildlife Department study needed to sustain the bays and estuaries, and this amount of water is higher than that actually needed to keep the bays productive. This issue has received much attention, and support is needed if conservation flows are ever going to be granted. The U.S. Fish and Wildlife Service (USFWS) wrote a letter of support for the San Marcos River Foundation's application for 1.15 million acre-feet of water that would remain in the river for wildlife. USFWS believes that providing a water right to the bays, as proposed by the San Marcos River Foundation, would be a crucial first step in guaranteeing that the bays would continue to function ecologically for all users to enjoy (Mendoza 2001b). It would be precedent setting in Texas for a water right to be designated as an inflow.

With the population of Texas predicted to double in the next 50 years, the Texas legislature has initiated a state-wide water planning effort. However, there is no direct mechanism in Texas water law to secure freshwater inflows to the bays and estuaries. Basically, the bays get whatever is left over, and portions of Texas rivers, including the Guadalupe, are already over-appropriated. In May 2007, the Texas Legislature adopted a sweeping plan intended to help ensure the state's future water supply. The legislation would require basins to develop recommendations to meet instream needs for specified bays and estuaries. The Texas Commission on Environmental Quality (TCEQ) will be required to adopt these recommendations as environmental flow standards and give consideration to water permit applicants based on conservation considerations like water levels, the environment and public need. The measure would establish the Environmental Flows Advisory Group, made up of appointed members, to oversee the process. This action was hailed by some Texas environmental groups. However, the amount of needed freshwater inflows will be determined through a stakeholder process and there is no guarantee how this will all turn out, or how identified instream needs will be met.

USFWS is very concerned about the impacts that planned diversions from the Guadalupe River would have on environmental water needs for adequate inflow to San Antonio Bay. A proposal included in the state water plan proposes a diversion at the mouth of the Guadalupe River, pumping at least 94,500 acre-feet annually back to San Antonio for municipal use. Additionally, as the San Antonio region grows, with population expected to double in the next 50 years (SAWS 2003), pumping from the Edwards Aquifer in times of drought threatens spring flows. To prevent impacts and avoid take of the whooping crane under the Endangered Species Act (ESA), USFWS has urged planners to quantify the freshwater inflow needs to maintain bay productivity and the critical habitat of the whooping crane and to account for those needs in future versions of the State Water Plan (Mendoza 2001a). Formal consultations on flow reductions must ensure that downstream water needs are met (Stehn 1998). The USFWS must take a strong stand on the inflow / whooping crane issue. On the Platte River in Nebraska, a section of designated critical habitat used by whooping cranes in migration, USFWS has determined that any new water withdrawals greater than 25 acre-feet constitutes a jeopardy call to the species under the ESA. Thus, a precedent has been set for USFWS action. All conservation groups need to do all in their power to ensure that adequate inflows from the Guadalupe River reach the bays.

Inflow level targets have not been identified to adequately support whooping cranes. Any withdrawal of water from the San Antonio / Gaudalupe River system is harmful to whooping cranes (T. Stehn, USFWS, Austwell, Texas, pers. comm.) except perhaps in times of flood. Inflow modeling is needed specifically for impacts to blue crab populations. Until this is done, water planners cannot judge how much harm river withdrawals will do to blue crabs and thus whooping cranes.

Measures to protect instream flow, fish and wildlife habitat, and freshwater inflows to bays and estuaries should be part of each regional water management plan (Sansom 2000). It is essential that the Region L water plan provide a mechanism for providing adequate inflows to San Antonio bay for the health and survival of the whooping crane population.

Any environmental analysis for groundwater use should include a detailed assessment of potential impacts to fish and wildlife found in springs, streams, rivers, and even inflows to bays and estuaries. An example of an area of concern is the Edwards Aquifer and the impacts reduced flows would have on the whooping crane found in the San Antonio and Aransas bays (Mendoza 2001a). Especially in times of drought, groundwater-fed springs can provide 70% of the inflow from the Guadalupe River. Comal and San Marcos Springs combined can make up over 30% of the base flow of the Guadalupe River and nearly 70% during periods of drought (Sansom 2000).

Management actions needed are to

a) model inflows and blue crab populations for the Guadalupe Estuary and relate to ecological needs of whooping cranes.

b) devise strategies to conserve blue crabs populations by maintaining required inflows.

c) maintain inflows to keep marsh salinities below 23 ppt. (Stehn pers. comm.)

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