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CLIMATE AND HABITAT FACTORS RELATED TO A LOCALIZED EXTIRPATION OF GIZZARD SHAD (*DOROSOMA CEPEDIANUM*)

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ABSTRACT—Gizzard shad are a riverine species commonly transplanted into manmade reservoir systems to provide prey for predatory game fish. Thermally limited, the range of their native distribution extends into the midwestern Great Plains. Following the harsh winter conditions of 2000-2001, numerous incidents of extensive gizzard shad die-offs were reported in eastern Nebraska during spring ice-out. In an effort to determine the breadth and extent of mortality, statewide fish population surveys conducted between 1994 and 2004 were examined, and it was found that gizzard shad were extirpated from seven flood-control reservoirs in a localized area of eastern Nebraska. Meteorological data confirmed that extreme cold and windy conditions were prevalent in the area during early December 2000, and may have been correlated to this unique extirpation event. Hydrologic connection to groundwater and wind sheltering may have protected smaller waterbodies from extirpation.

Key Words: climate conditions, extirpation, gizzard shad, habitat factors, winterkill

INTRODUCTION

It is becoming increasingly important for natural resource managers to be able to predict the impact of a species introduction on an ecological system. In the United States, an estimated 762 nonindigenous aquatic species have been introduced over the last century (Benson 1999). The construction of predictive analytical models to assist managers is made exceedingly difficult by the complexity of ecological systems. The success of a modeling approach is often proportional to the quantity and quality of information related to the species and systems involved (Fuller and Drake 1999). As an example, Leach (1999) postulated that global warming and the resulting altered thermal regimes would accelerate the northern shift of southern aquatic species through range expansion. Matthews and Zimmerman (1990) suggested that many species occupying streams in the southern Great Plains were potentially vulnerable to extinction due to global warming, as few northward dispersal avenues were available. Therefore, detailed knowledge of a species interaction with its environment is essential to developing future predictive models to aid natural resource managers in decision-making processes.

Gizzard shad (*Dorosoma cepedianum*) are native to the large river basins in the central and eastern United States, preferring low-gradient, slow-moving warmwater habitats (Pflieger 1975; Becker 1983). Primarily a schooling, filter-feeding planktivore, they are able to switch to detritivory in response to low plankton conditions (Dettmers and Stein 1996). Natural river systems typically have associated complexes of wetlands, chutes, backwaters, and oxbow lakes, with varying spatial and temporal connections between the floodplain and main channel flows. Periodic flooding provides dispersal opportunities for many riverine species. Today, most of our large rivers have been altered and impounded, reducing connectivity with these floodplain water complexes.

Considered valuable prey for sport fish species (DeVries and Stein 1990), gizzard shad have been stocked extensively into manmade reservoirs outside their native historic distribution, often impacting zooplankton communities (Moyle and Cech 1988; Dettmers and Stein 1992, 1996) and competing with juvenile fish for plankton resources (Michaletz 1997). In southern states, gizzard shad biomass can be large enough to dominate reservoir fish communities, with resulting negative impacts to game fish species (Noble 1981). A common practice for managers of Great Plains reservoirs outside or near the extent of the gizzard shad native distribution is to annually collect adult broodstock from thermal refuge populations (e.g., below power-plant discharge) and transfer them to receiving waters in the spring prior to spawning, thus providing an annual infusion of prey for predator populations (Eichner and Ellison 1983).

Gizzard shad distribution is thermally limited, as they increasingly succumb when water temperatures decrease below 4°C (Wehr 1976). The incidence of winter-related mortality of gizzard shad populations increases near the extent of their range. Bodola (1965) described several massive die-offs occurring in Lake Erie. Lake Rathburn, Iowa, in November 1971 experienced a large die-off of gizzard shad when water temperatures in shallow areas were between 2.2° and 3.3°C (Mayhew 1975). In New Mexico, gizzard shad winter-mortality events have occurred in Conchas, Caballo, and Elephant Butte lakes. Jester and Jensen (1972) observed winter mortality events ranging from 3 to 11 days in these lakes when the water temperatures dropped below 3.3°C with juvenile gizzard shad more vulnerable than older fish. Mortality rates differed by gizzard shad age classes, waterbody size, and each location, with minimum water temperatures ranging from 2.8° to 3.3°C and occasionally ranging below 2.2°C.

Small, shallow waterbodies in the midwestern Great Plains can be susceptible to these conditions during late fall and early winter, especially in relation to storm events typified by windy conditions that inhibit ice formation and promote the growth of a mixed layer of cooling water. The purpose of this investigation was to determine the extent of gizzard shad winterkill by examining fish population sampling data, and to identify possible climatic factors or habitat conditions related to the observed extirpation event in eastern Nebraska during the winter of 2000-2001.

METHODS

I examined the database of standard survey information compiled and maintained by the Fisheries Division of the Nebraska Game and Parks Commission (NGPC) to investigate the extent of the 2000-2001 winterkill event and determine whether it resulted in partial or complete extirpation of populations. A review of fishery surveys conducted between 1994 (upon implementation of the statewide database) and the fall of 2000 identified populations containing gizzard shad prior to the winterkill event. Surveys of these same populations conducted between 2001 and 2004 with standardized sampling gear (fall-season experimental mesh gill nets, spring and fall trap nets and beach seines) determined our study waters and were examined for subsequent catches of gizzard shad. Catch rates (abundance/sampling effort), sampling gear, and aquatic habitat types as described by Porath and Hurley (2005) were recorded. Categorization of aquatic habitat types was based on similar physical and hydrologic aquatic conditions (e.g., flood-control, irrigation, or power-generation reservoirs, borrow or sand/gravel mining pits, ponds under 12 ha). Gizzard shad are also transplanted as a prey source in select waterbodies in Nebraska reservoirs. A fish-stocking database maintained by the Fisheries Division was also reviewed to identify waters stocked with gizzard shad during the study period.

Climate data, including temperature, wind velocity, and precipitation, was available from a local weather station and compiled by the High Plains Regional Climate Center at the University of Nebraska–Lincoln for the months of November and December from 1998 through 2004. Mean temperature, days with maximum temperatures <0°C (32°F), days with minimum temperatures <0°C (32°F), days with minimum temperatures <-17.8°C (0°F), wind velocities, and precipitation (water equivalent) and snowfall for each month were compared to averages derived from normal standards and/or periods of record. Deviations from normal were plotted for the November through December time period (late fall and early winter, prior to ice formation) to determine in which years climate variables may have played a role in any extirpation events. Hourly mean wind velocities and air temperatures were examined to identify periods in which extreme cooling and forced convection may have prevented ice cover formation and resulted in thermal conditions that were physiologically detrimental or lethal to gizzard shad.

RESULTS

Standard survey methods collected gizzard shad from 41 waters across the state between 1994 and 2000 that were also sampled in 2001-2004 (Table 1). The diversity of aquatic habitat types populated with gizzard shad included a small pond (<0.12 km^2), eight borrow or sand/gravel mining pits, 12 flood-control reservoirs, and 20 irrigation or power-generation reservoirs ranging in size from 12 to 121 km^2. The majority of these waters are found in the southern half of the state or within the Missouri River floodplain on the eastern and northeastern border and overlapping the traditional distribution ranges described by Pflieger (1975) and Becker (1983). Lake Minatare is a high plains irrigation and/or power-generation reservoir outside the native range distribution

TABLE 1
NEBRASKA WATERS INHABITED BY GIZZARD SHAD (*DOROSOMA CEPEDIANUM*) BETWEEN 1994 AND 2004

	Habitat type	**Surface area (km2)**	**Presence during sampling**	
			1994-2000	**2001-2004**
Western High Plains Region				
Lake Minatare	Irrigation & power	0.07	Yes	Yes*
North Central Region				
Calamus Reservoir	Irrigation & power	20.70	Yes	Yes
Davis Creek Reservoir	Irrigation & power	4.60	Yes	Yes
Northeast Region				
Cottonwood Lake	Borrow/mining pits	1.00	Yes	Yes
Fremont #18	Borrow/mining pits	0.03	Yes	Yes
Willow Creek Reservoir	Flood control	2.80	Yes	Yes**
Skyview Lake	Flood control	0.20	Yes	Yes
Lewis & Clark Reservoir	Irrigation & power	107.20	Yes	Yes
Red Fox WMA	Small pond	0.09	Yes	Yes
Southwest Region				
Enders Reservoir	Irrigation & power	6.90	Yes	Yes
Jeffrey Reservoir	Irrigation & power	4.50	Yes	Yes
Lake Maloney	Irrigation & power	6.50	Yes	Yes
Lake McConaughy	Irrigation & power	121.40	Yes	Yes
Medicine Creek Reservoir	Irrigation & power	7.50	Yes	Yes
Red Willow Reservoir	Irrigation & power	6.60	Yes	Yes
Sutherland Reservoir	Irrigation & power	12.10	Yes	Yes
Swanson Reservoir	Irrigation & power	20.10	Yes	Yes
Southeast Region				
Louisville #1	Borrow/mining pits	0.02	Yes	Yes
Two Rivers #1	Borrow/mining pits	0.02	Yes	Yes
Two Rivers #2	Borrow/mining pits	0.01	Yes	Yes
Two Rivers #3	Borrow/mining pits	0.02	Yes	Yes
Two Rivers #4	Borrow/mining pits	0.02	Yes	Yes
Bluestem Reservoir	Flood control	1.30	Yes	**No**
Branched Oak Reservoir	Flood control	7.30	Yes	Yes
Conestoga Reservoir	Flood control	0.93	Yes	**No**
East Twin Reservoir	Flood control	0.85	Yes	**No**
Glenn Cunningham Reservoir	Flood control	1.58	Yes	Yes
Pawnee Reservoir	Flood control	2.99	Yes	**No**
Stagecoach Reservoir	Flood control	0.79	Yes	Yes
Standing Bear Reservoir	Flood control	0.55	Yes	**No**
Wehrspann Reservoir	Flood control	0.99	Yes	**No**
Zorinsky Reservoir	Flood control	1.03	Yes	**No**
South Central Region				
Morman Island Middle	Borrow/mining pits	0.08	Yes	Yes
Elwood Reservoir	Irrigation & power	5.38	Yes	Yes
Gallagher Canyon Reservoir	Irrigation & power	0.74	Yes	Yes
Harlan County Reservoir	Irrigation & power	54.63	Yes	Yes
Johnson Lake	Irrigation & power	11.33	Yes	Yes
Midway Reservoir	Irrigation & power	2.46	Yes	Yes
Phillips Canyon Reservoir	Irrigation & power	0.60	Yes	Yes
Plum Creek Canyon Reservoir	Irrigation & power	1.02	Yes	Yes
Sherman Reservoir	Irrigation & power	11.51	Yes	Yes

Note: Sampling indicates whether gizzard shad were collected before and after the severe winter of 2000-2001.

* Maintained by broodstock transplants.

** Supplemented by broodstock transplants.

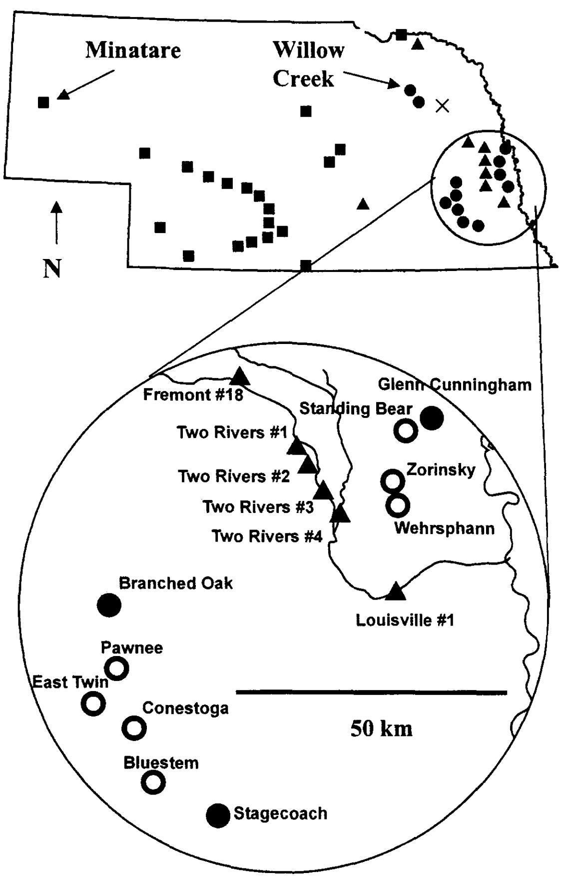

Figure 1. Locations of Nebraska waterbodies supporting gizzard shad populations between 1994 and 2004. Waterbody types are indicated as follows: squares = irrigation and power generation reservoirs; circles = flood control reservoirs; X = small pond; triangles = borrow and sand/gravel mining pits. The two populations maintained or supplemented by broodstock transplants (Minatare and Willow Creek reservoirs) are labeled in the state map. The 50 km radius inset of eastern Nebraska indicates which waters experienced a localized extirpation of gizzard shad (open = extirpated, solid = survived) during the winter of 2000-2001.

of gizzard shad and is maintained by annual broodstock transplants. Willow Creek is a flood-control reservoir in northeast Nebraska that receives periodic supplemental stockings.

Thirty-four of the 41 waterbodies maintained gizzard shad populations through the winter of 2000-2001. The seven exceptions were flood-control reservoirs, all located within a 50 km radius in eastern Nebraska (Fig. 1). Within the same radius were an additional three flood-control reservoirs and six borrow or sand/gravel mining pits that did not experience gizzard shad extirpation. Validation of extirpation versus a temporary decline in abundance was documented through multiple sampling attempts (Table 2) from 2001 to 2004 on all but two flood-control reservoirs (Bluestem and Cunningham) and one borrow or sand/gravel mining pit (Fremont #18). In the two flood-control reservoirs (Branched Oak and Stagecoach) sampled in 2001 in which gizzard shad were not extirpated, their catch rates did decline substantially.

CLIMATE DATA

Air temperatures for the November to December period in 2000 were unusually cold (Fig. 2). Mean monthly air temperatures in 2000 were 0.17°C (32.3°F) in November, 3.6°C (6.5°F) below normal and 6.3°C (11.4°F) cooler than 1998, and 8°C (14.4°F) less than 1999. The mean monthly air temperature of -9.0°C (15.8°F) in December 2000 was 8.6°C (15.5°F) cooler than 1998, and 8.8°C (15.9°F) below 1999. For 22 of the 31 days in December 2000, the maximum high air temperature was below 0°C (32°F), twice the normal of 11 days, 14 days more than in 1998, and 17 more than in 1999. For nine days, the maximum high air temperature was below -17.8°C (0°F), seven days more than both 1998 and 1999. The UNL High Plains Regional Climate Center documented December 2000 as the third coldest on record from 1887 to 2000, and the period from November 6 to December 25 as the second coldest in 114 years (unpublished data, UNL High Plains Regional Climate Center).

More snow fell in December 2000 than any other year in the study period, although water-equivalent precipitation was below normal (Fig. 3). The UNL High Plains Regional Climate Center ranked December 2000 as the fifth snowiest in 101 years (unpublished data, UNL High Plains Regional Climate Center). A substantial portion of the snowfall was associated with the passage of four consecutive storm systems beginning on December 10, 2000. The first storm produced a 41-hour time period in which the mean air temperature was -14.2°C (6.3°F) and winds averaged 6.26 m/s (Fig. 4). These parameters exceed those predicted to produce frazil ice, which forms under supercooling conditions in flowing rivers (Williams 1973), and the wind velocity was greater than the <5 m/s (converted from 11.2 mph) threshold predicted by Gu and Stefan (1990) required to permit ice formation on freshwater lakes. These conditions likely promoted extensive cooling and growth of the mixed layer during this time period.

Ice thickness and surface area coverage most likely progressed rapidly following the decrease in wind velocity on December 12-13 (<3.5 m/s) and air temperatures remained below -8.3°C (19°F). Although winds did increase to near threshold conditions by midday on December 14,

TABLE 2
GIZZARD SHAD SAMPLING AND ABUNDANCE IN WATERS WITHIN A 50 KM RADIUS IN EASTERN NEBRASKA

Aquatic habitat type	Area (km2)	Volume (1000 m3)	Mean depth (m)	Area to volume ratio	Inflow (m3/s)	Abundance										
						1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Borrow and sand/gravel mining pits																
Fremont #18	0.03	118.4	3.7	0.00025	ground						9.5		11.5			
Louisville #1	0.02	103.6	3.7	0.00019	ground				0.5^{F}	20.5				7^{F}		0.5^{F}
Two Rivers #1	0.02	62.9	3.1	0.00031	ground				0.3^{F}	32.5		2.8^{F}	26.5	26		23.5
Two Rivers #2	0.01	34.5	3.1	0.00028	ground						0.3^{F}			47.5		38.8
Two Rivers #3	0.02	97.4	4.3	0.00020	ground					10.5		1.5^{F}	14	25		41
Two Rivers #4	0.02	64.1	3.1	0.00031	ground									18		46
Flood control reservoirs																
Bluestem	1.30	3122.0	2.7	0.00041	0.16		35	2.5				28.7			0	
Branched Oak	7.30	30946.0	3.4	0.00023	1.12	69.3	11	14.5	57.8	0.5	24.5	71.5	2	33.25	13.8	15.8
Conestoga	0.93	2358.0	7.5	0.00039	0.20	29.4	17.6^{S}	27	25.3	112.5	3.5^{F}	42.8	0	0	0	0
Pawnee	2.99	9637.0	3.7	0.00031	0.29	29.5	30.3	31.3	19.8	23.6	41.5	35	0	0	0	0
Stagecoach	0.79	1790.0	3.4	0.00044	0.10		26.8	23.3	98	4.0^{F}	30	26.3	0.5	61.3	45	12.3
East Twin	0.90	2666.0	3.7	0.00033	0.14	14.5	69.8	48.3	14.8	92.5	0.1^{F}	58.8	0	0	0	0
Wehrspann	1.00	3308.0	3.4	0.00030	0.09		0	0	23.7	52.8	0.1^{F}	4.6^{F}	0	0	0	0
Glenn Cunningham	1.60	4024.0	3.4	0.00040	0.29	43.7		20.8	106.7	91						48
Standing Bear	0.60	1585.0	3.4	0.00037	0.04	63.5					63.3	39.8	0	0	0	0
Zorinsky	1.00	3746.0	1.3	0.00026	0.04		77.7	54.3	13.6^{F}	23.3	0.3^{F}	0.4^{F}	0		0	0

Notes: Volume of inflow is in annual average meters per second (ground = hydrologically connected but rate is unknown), and abundance (catch per unit effort) is by gear type (all are experimental gill nets catches except F = frame net and S = beach seine) from 1994 to 2004.

air temperatures remained below freezing, except for two hours, throughout the rest of December 2000. High winds associated with three small storm systems returned to the area from December 16 to 21. The role of convective forces and the extent of surface area cover and ice thickness formed prior to these storms likely varied between the individual waters, as did their resistance to wind breakup during the following six days. However, calm conditions (<1.0 m/s) existed for only 16 hours, with a single six-hour period of no recorded wind velocity between December 12 and 15.

DISCUSSION

Spring observations of gizzard shad overwintering mortality are relatively common and vary from year to year. Initially assuming a larger than normal die-off had occurred, we were not expecting any extirpation of populations since we had no historical documentation of similar events. Following the annual fall surveys in 2001, we expected that, even in waters where no gizzard shad were sampled, the population had been temporarily suppressed below the detection threshold of our sampling gear, and that their numbers would rebound in 2002. And as expected, the low catch rates recorded at Branched Oak and Stagecoach reservoirs in 2001 were temporary and were followed by increased abundance in 2002 (Table 2). However, continued sampling through 2004 revealed that gizzard shad extirpation had in fact occurred on seven flood-control reservoirs but not in any borrow or sand/gravel mining pits.

All of the waterbodies in the extirpation area (Fig. 1) were subjected to similar meteorological conditions. The below-normal mean air temperatures and above-normal wind velocities prior to the December 10-12, 2000, storm event established lower mean water-column temperatures than previous years. During the storm, wind directions remained northerly between 320° and 30°. Findikakis and Law (1999) found that sustained convective winds, in velocity and direction, contribute more effectively to the growth of the mixed layer than short-duration interrupted winds characterized by switching directions.

A unique physical property of the water molecule is that it imparts its highest density in a liquid state (4°C or 39.2°F) rather than in its solid form, allowing inverse thermal stratification to occur as air temperatures drop

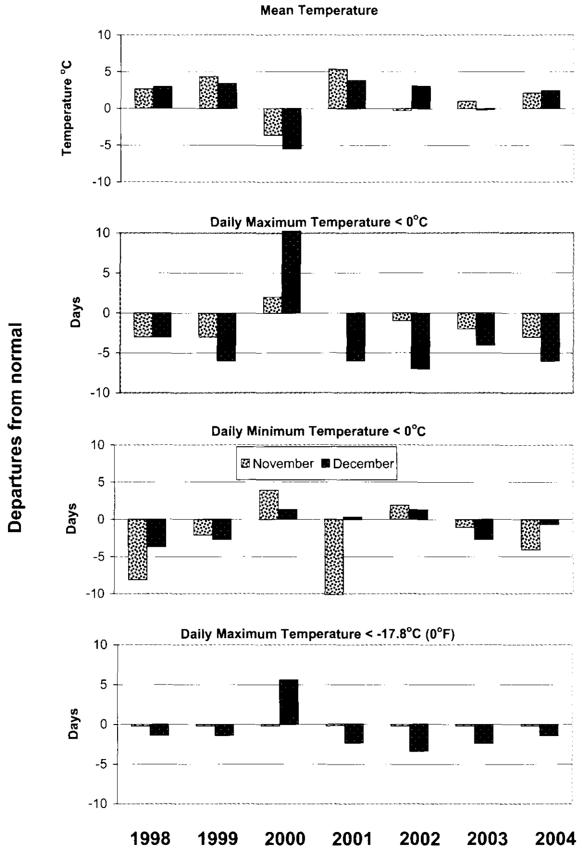

Figure 2. Dry-bulb air temperature parameter departures from normal in the months of November and December for Lincoln, NE, from 1998 to 2004. Departure differences, provided by the UNL High Plains Regional Climate Center, compare the observed average with the 30-year standard climate normal averages.

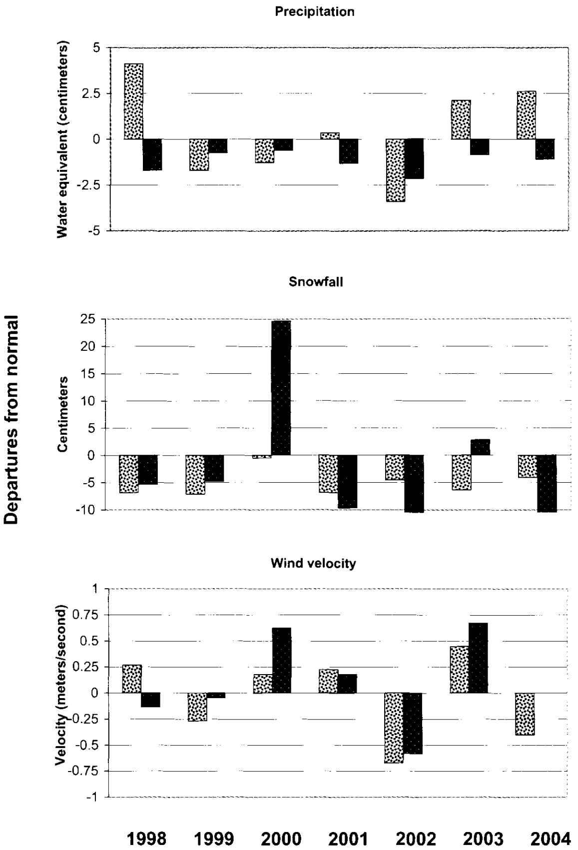

Figure 3. Precipitation, snowfall, and wind velocity parameter departures from normal in the months of November and December for Lincoln, NE, from 1998 to 2004. Departure differences, provided by the UNL High Plains Regional Climate Center, compare the observed average with the 30-year standard climate normal averages.

below freezing at the water surface. Ice formation generally occurs on cold, calm nights on small freshwater lakes. Models incorporating surface cooling and convective forces have been developed to estimate permanent ice formation and duration for natural lakes in Minnesota (Fang et al. 1996). The estimated freeze-up date must take into account the effect of wind stress on ice thickness, which must be sufficient to resist breakup (Gu and Stefan 1990). If ice thickness or surface coverage is insufficient to withstand daytime heating or wind forces, then the cover breaks apart until conditions permit formation a second time (Ashton 1986). The formation of ice cover substantially slows subsequent cooling from wind-mixed subzero air and again establishes inverse stratification where temperatures range from 0°C under the ice to > 4°C near the bottom.

Convective forces (wind) easily break down inverse stratification and continue to mix the surface layer (USACE 2002). Under severe weather conditions, the surface mixed layer can expand and become supercooled in cases where severe wind and waves prevent ice-crystal congelation (Donchenko 1973). Isothermy, to less than 1°C, has been observed frequently before the formation of ice cover, particularly in large lakes that are subject to substantial wind action (Wetzel 2001). Shallow lakes are also subject to isothermy from wind-mixed conditions (Michael 1968). Heidinger (1983) described how a breakdown in winter stratification could result in water temperatures approaching 0°C throughout the water column, resulting in extensive gizzard shad mortality unless thermal refugees are available.

The difference in aquatic habitat characteristics between flood-control reservoirs and borrow and sand/gravel mining pits likely produced different internal thermal conditions prior to and during these storm events. Similarly, Gao and Stefan (1999) found that temperature

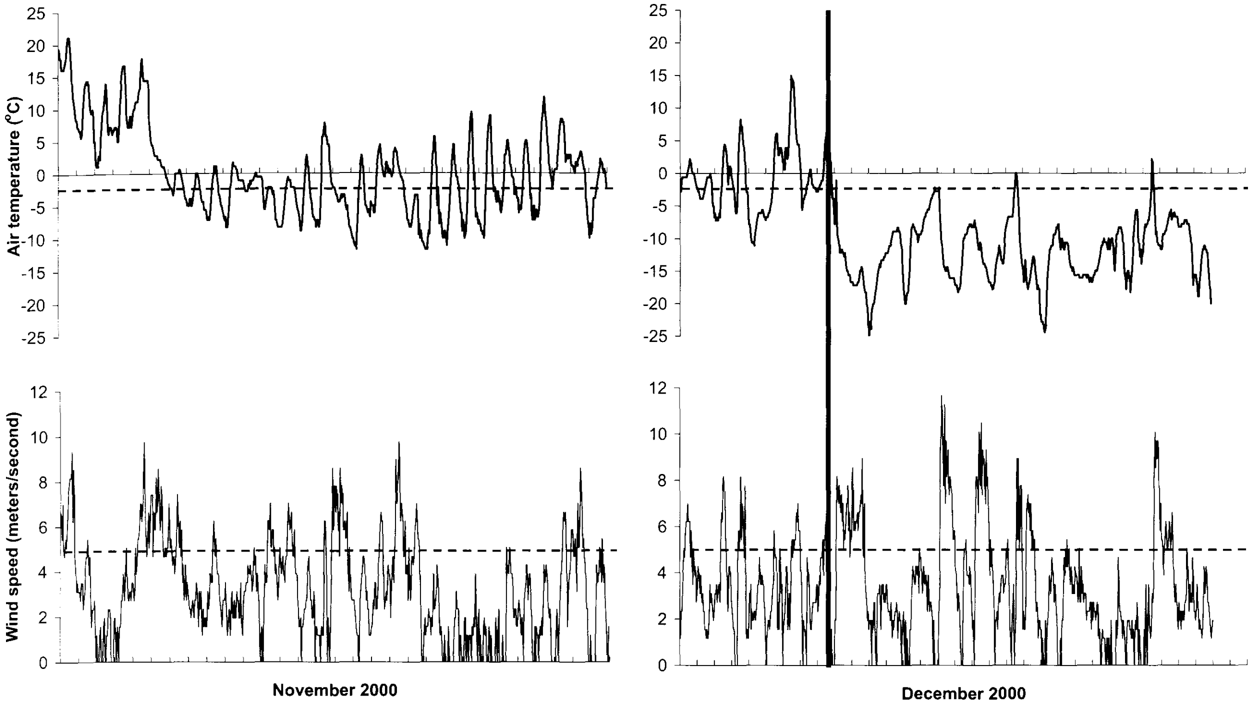

Figure 4. Hourly air temperature (dry bulb) and wind speed for the months of November and December 2000 monitored by the NOAA weather station at the Lincoln, NE, municipal airport. The dark vertical line indicates the onset of a series of winter storms. The dashed lines are the temperature (28.4°F [-2°C]) and wind speed (11.2 mph [5 m/s]) thresholds for ice-cover formation (Gu and Stefan 1990).

regimes in Minnesota lakes varied by climate, geography, surface area, and depth. And Donchenko (1973) reported that the mean freeze-up period ranged between 6 and 32 days for reservoirs from different regions in Russia. Conditions within different aquatic habitat types vary as a function of their landscape location and physical characteristics. In the area of gizzard shad extirpation, borrow and sand/gravel mining pits lie in a wooded valley adjacent to the Platte River, while the flood-control reservoirs are located in the upper portions of watersheds.

Flood-control reservoirs differ from borrow or sand/gravel mining pits by their water sources, surface areas, and protection from convective forces. Surface runoff provides the majority of inflow to flood-control reservoirs. By design, these reservoirs are located to minimize storage volume occupied by base flows and maximize their capture of large runoff events (e.g., Bluestem Reservoir was designed by the USACE to control 20.3 cm [7.99 inches] of runoff over the drainage area of 43 km^2 [16.6 miles^2]). Borrow and sand/gravel mining pits have little inflow but maintain stable water levels from the hydrologically connected groundwater, which also serves as a heat source similar to those provided by sediments throughout the winter (Gu and Stephan 1990). Michel (1971) cited several estimates of heat conduction ranging from 29.4-529.3 J/m^2/day (0.3-5.4 Btu/ft^2/day). The hydrologic connection of borrow and sand/gravel mining pits to groundwater likely plays a key role in providing stable thermal conditions even during extreme winter storm events. Surface and groundwater inflow heating of the water column in the winter is relative to their volume ratio with the waterbody as well as their thermal properties. However, perennial surface and subsurface flows may still provide small areas of refuge even on very large bodies of water.

Although mean depth (2.5-4.3 m) and ratio of surface area to water volume (0.00019-0.00044 km^2/m^3) was similar for all waters, the largest of the borrow and sand/gravel mining pits in the extirpation area was only 0.03 km^2 in surface area and 118,462 m^3 in volume. The flood-control reservoirs ranged from 5.5 to 7.2 km^2 and from 1,700,000 to 30,800,000 m^3. Hondzo and Stefan (1993) described differences in wind sheltering, through reduction in fetch, and found that trees or buildings along shorelines shelter a larger proportion of the small lakes than large ones. The mature woodlands of the river floodplain surrounded the borrow and sand/gravel mining pits, affording substantial protection from convective forces. Even though the flood-control reservoirs in the extirpation area are also ringed with mature trees, they are afforded only minimal protection since the smallest flood-control reservoir, Standing Bear (0.6 km^2), has a 20-fold larger surface area. The remaining area is still subjected to accelerated heat transfer from the water surface and the resistance to ice-cover formation by the effects of wind (Stefan and Ford 1975). It is likely that fetch reduction from wind sheltering afforded by the surrounding woodlands provided proportionally more benefit to the borrow or sand/gravel mining pits than to the flood-control reservoirs during the December 2000 storm events. It may have been sufficient to prevent significant growth of the mixed layer, preventing extirpation of gizzard shad in these waters.

Gizzard shad evolved and adapted to habitat conditions present in natural river systems. With the altering of river connectivity with floodplain complexes, the ability of a population to respond to localized extirpations with subsequent colonization efforts is eliminated or reduced in frequency. In hydrologically unique, manmade aquatic systems like flood-control reservoirs, borrow and sand/gravel mining pits, and irrigation and power-generation reservoirs, suitable habitat conditions must be present to provide refuge during extreme weather conditions or extirpation may occur.

CONCLUSIONS

The extreme weather during the winter of 2000-2001 likely produced the thermal conditions sufficient to extirpate gizzard shad from 7 of 10 flood-control reservoirs in eastern Nebraska. By contrast, none of the fish populations in borrow and sand/gravel mining pits within the same area experienced extirpation or a significant reduction of gizzard shad. While wind sheltering and groundwater inflows likely buffered these borrow or sand/gravel mining pits from extreme climate conditions, we found no bifurcation in the habitat characteristics segregating the three flood-control reservoirs from the seven in which extirpation did occur. The sudden selective extirpation of gizzard shad from aquatic assemblages will likely benefit juvenile fishes that directly compete for plankton resources. Piscivore species may benefit or be impacted based on their size. Large piscivores may experience reduced availability of once-abundant fish prey, while smaller predators may benefit from the increased abundance of zooplankton and small young-of-year fishes that once competed with gizzard shad.

As expanding wildlife populations interact with changing habitat conditions induced through either climatic or anthropogenic events, managers of natural resources should expect reduced success in colonization efforts by gizzard shad approaching the extent of their native range. The time frame for determining successful colonization should be sufficiently elastic to encompass the range of conditions interacting with these dynamic systems

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