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The Interactions Between *Aythya valisineria* (Canvasback Duck) and *Vallisneria americana* (Wild Celery): Effects on Restoration in the Upper Mississippi River.

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Introduction

Aythya valisineria (canvasback duck) is a migratory duck found throughout North America. Canvasback ducks migrate from Alaska and western/central Canada to Mexico, the San Francisco area, and the Atlantic and Gulf Coasts (Kahl, 1991). They traditionally feed on *Vallisneria americana* (wild celery) in fall, before and during migration, and invertebrates in winter, when foraging is more difficult. However, most people who know of the canvasback duck know it more for its taste then for its place in nature. The taste of the duck is so well liked that for many years over-hunting was a large problem. However, recent restrictions on hunting, with strict canvasback duck bag limits, have eliminated overhunting as a factor in population loss.

Crucial migratory habitat for canvasbacks occur along the Upper Mississippi River, specifically on Navigation Pools 7,8,and 9, found near Lacrosse, Wisconsin. Lake Onalaska, in Pool 7, had an estimated peak population in of 107,500 in 1979, while in 1992 the peak population was just 49,575 (Korschgen, C.E., Unpublished Study *in* Korschgen et al. 1996). These declines have been speculated to have been caused by several factors, including boating disturbances in the area that decrease the ability of canvasback ducks to feed successfully (Korschgen et al. 1985, in Kenlow et al. 2003). However, the strongest factor appears to be a decline in the abundance wild celery in the area, which is key to autumnal migration success for canvasback ducks (Lovvorn, 1987 in Lovvorn, 1989). This paper will address the relationship between wild celery and canvasback ducks and will show how wild celery restorations affect canvasback duck populations.

The Importance of Wild Celery To Canvasback Ducks

Along their migratory route, canvasbacks need to stock up on energy in the form of body fat (Kendeigh et al. 1977 in Korschgen and Green, 1987). To do this, most migration patterns develop so that there are strategic food stops along the way (Korschgen and Green, 1987). One of the foods that canvasback ducks have traditionally used to increase body fat are the winter buds of wild celery (McAtee, 1917 *in* Korschgen and Green, 1988).

Canvasback ducks appear to prefer wild celery for the nutritional value of their winter buds. The other main food sources available to canvasback ducks are small clams (Jorde et al. 1995) along with other invertebrates and also *Sagittaria rigida* (stiff arrowhead) tubers (Korschgen and Green, 1987). There has been research on canvasback ducks eating wild celery and *Macoma balthica* (Baltic Clams), and the nutritional differences between the two diets. Wild celery is high in carbohydrates, while invertebrates like Baltic Clams are high in protein (Korschgen and Green, 1987). This is an important difference, because carbohydrates are more easily turned into fats than are proteins (Ricklefs, 1974, in Korschgen and Green, 1987).

Stored energy is the most important autumn food source for canvasbacks, as most of their time is spent flying instead of feeding. The time differential between flying and feeding is the reason wild celery is the preferred diet in fall. Protein is more easily used quickly then are carbohydrates, thus clams are normally the diet in spring, when immediate energy is more important than stored energy. However, because of reduced populations of wild celery, clams are becoming an increasingly important diet throughout the year. This difference in nutritional value is exemplified by two research examples: baltic clams in Chesapeake Bay and stiff arrowhead tubers in the Upper Mississippi River.

Chesapeake Bay and Baltic Clams
Canvasback ducks in the Chesapeake Bay area lose an average of 8-10% biomass from January to March (Nichols and Haramis, 1980 in Jorde et al. 1995). Biomass loss and recovery of biomass are both greatly affected by the Canvasback's diet and on its feeding opportunities (Loesch and Kaminski, 1989 in Jorde et al. 1995). Wild celery in Chesapeake Bay has been virtually eliminated by pollution and resuspended sediment caused by heavy boat traffic. Coinciding with this loss of wild celery is a decline in the canvasback population (Orth and Moore, 1991 in Jorde et al. 1995) (Haramis, 1991 in Jorde et al. 1995). With this loss in their preferred food source, canvasback ducks were forced to eat Baltic clams to survive the winter (Lovvorn, 1989). Unfortunately, a clam diet is vastly inferior to a wild celery diet. Canvasback ducks that ate clams gained a mean of 23 g / day, while canvasback ducks fed wild celery gained 32g / day (Jorde et al. 1995). The comparison means that canvasback ducks can gain body mass 1.5 times as fast by eating wild celery over eating Baltic clams. Over the course of these tests, canvasback ducks fed wild celery also maintained their body mass longer.

The effects of eating clams instead of wild celery in autumn and winter are profound. In a simulation of possible winter situations, canvasback ducks were not allowed to eat for a period of days. Canvasback ducks that ate clams lost 86 g, while canvasback ducks that were fed wild celery lost only 4 g. Also, after a period of starvation, canvasback ducks that were fed clams ad libitum (until satisfied) gained back 52-71% of their original body mass over 4 days, while canvasback ducks fed wild celery ad libitum gained back 83-90% of their original body mass over the same period of time (Jorde et al. 1995). This clearly shows that, at least in the case of wild celery winter buds and Baltic clams, wild celery is the far better autumn and winter food, as the canvasback ducks that eat it gain more and lose less body mass. In nature this trend may be even more pronounced, as foraging efficiency is lower for Baltic clams than it is for wild celery (Jorde et al. 1995; Lovvorn, 1989). This addresses what effects occur from canvasback ducks eating food normally left for winter. Similarly, effects are seen when canvasback ducks eat fall food, but in higher amounts then they traditionally would.

The Upper Mississippi River Pools and Stiff Arrowhead Tubers
In the Upper Mississippi River Pools, a supply of wild celery is still available to canvasback ducks, however, it is far less abundant than it was thirty years ago (Kahl, 1991). Even before this decline in wild celery population, canvasback ducks in the Upper Mississippi River Pools fed on stiff arrowhead tubers. In a study from October of 1979 to November of 1980, 42.5% of food volume found in studied birds was wild celery, while 56% was stiff arrowhead tubers. However, of the total time canvasback ducks spent feeding, 56% was spent feeding exclusively on wild celery. With the higher early level of feeding on wild celery, the canvasback ducks that arrived early likely claimed the wild celery area, and the canvasback ducks that arrived later were effectively forced to settle for the stiff arrowhead tubers. Also, for the most part, the ducks fed selectively, either taking exclusively wild celery or exclusively stiff arrowhead tubers. This lead to a bias in the study because the wild celery was located in an area from which collecting birds was more difficult (Korschgen and Green, 1987). The collection difficulty would lead to the study showing a higher percentage of arrowhead tubers being eaten then actually occurred. This means that wild celery tubers are more important to canvasback ducks than this study shows.

Wild celery and stiff arrowhead tubers have very similar nutritional values. However, wild celery buds are soft compared to stiff arrowhead tubers, making them more easily digested, potentially contributing to their being preferred as a food source (Korschgen and Green, 1987). The relative softness of wild celery may actually allow a canvasback duck's digestive system to process it faster, allowing the canvasback to eat more, and thus canvasback ducks can fatten up more quickly by feeding on wild celery then if they feed on stiff arrowhead tubers (Korschgen and Green, 1987). Small invertebrates are in the Upper Mississippi River, as they are in Chesapeake Bay, and canvasback ducks do eat them. However, canvasback ducks are eating invertebrates more now that wild celery is becoming scarce (Kahl, 1991). Unfortunately, like Baltic clams, they are not as helpful to canvasback ducks as wild celery. The two previous examples show how important autumn wild celery availability is for canvasback ducks in the Upper Mississippi River Pools.

Connectivity of Wild Celery Abundance and Canvasback Duck Population

Many past documented cases point to there being a fairly direct correlation between wild celery abundance and the canvasback population, such as the case in Chesapeake Bay. The correlation is also true in the case of the Upper Mississippi River Pools, where the effects of the interactions between these species can be seen.

In the mid 1960's up to the early 1980's, a shift was seen in Canvasback populations, with feeding stops moving from sites in greater Minnesota, Iowa, and Wisconsin to the Upper Mississippi River Pools (Mills, et al. 1966. in Korschgen and Green, 1987) (Trauger and Serie, 1974. in Korschgen and Green, 1987) (Serie, et al. 1983 in Korschgen and Green, 1987). At the time of the shift in migratory stopover, celery numbers were declining in the original Minnesota, Iowa, and Wisconsin sites. Meanwhile, the Upper Mississippi River Pools were seeing an increase in wild celery, likely due to post-dam vegetation succession (Trauger and Serie, 1974. in Korschgen and Green, 1987) (Korschgen, Unpublished data. in Korschgen and Green, 1988). This relationship suggests the ducks followed the wild celery into Upper Mississippi River Pools.

There was also a case at the Upper Mississippi River Pool 8 in 1978-1979 when the wild celery experienced an abrupt decrease in area, by 550 ha, a full 80% of the total wild celery in Pool 8. The drop in wild celery abundance coincided with a drop of 92% of the use-days by canvasback ducks in fall (Korschgen, Unpublished data from Biol. Survey, in Korschgen and Green, 1987).

Causes of Celery Decline

Many sites, from the Upper Mississippi River, to the Detroit River (Schloesser and Manny, 1990. *in* Kimber and van der Valk, 1994) have seen a decrease in abundance of wild celery, caused by a few different factors. For the Upper Mississippi River Pools, there are two main reasons for the loss of wild celery abundance. The drought of 1988-1989, and the flood of 1993, caused major declines in quality and abundance of wild celery (Hohman et al. ND) (Korschgen, et al. 1997).

The Drought of 1988-1989

One major hypothesis exists regarding how the drought of 1988-1989 caused the large die off in wild celery that was seen at that time (Kahl, 1991) (Kimber and van der Valk, 1994). The hypothesis states that the low water levels caused high water temperatures, long hydraulic residence times, low dissolved oxygen levels, and a higher than normal concentration of nutrients from normal discharges from municipal treatment plant effluent and from sediment (Lennartson et al. letter, 1989. in Kahl, 1991). This combination of warm water and increased nutrient level caused very high epiphyton and phytoplankton populations, creating turbid water that allowed very little light to pass through the water to the water celery (Kimber and van der Valk, 1994). The low light levels shaded and smothered the wild celery, stressing the plants during the winter bud formation stage, and this shading and smothering is likely still affecting wild celery growth to this day because of the long residence times. Any plants that survived either produced no buds, or produced small and weak buds. With still high phytoplankton populations and sediment that had been resuspended, the high water turbidity persisted though spring of 1989, further stressing the remaining plants (Kahl, 1991) (Kimber and van der Valk, 1994).

The Flood of 1993
Massive flooding occurred in 1993, following the drought, likely causing further declines to populations for wild celery. This population decline likely resulted from the increased water depth and water velocity, typical of flood conditions. Increased velocity is not enough to kill wild celery; however, water depth is. If water containing wild celery is much deeper then two meters, female plants cannot extend their peduncles to the surface to allow for reproduction. Also, if water speed goes over 0.3 m/s, pollination appears to become impossible (Sullivan and Titus, 1996). The floods lasted for the majority of the summer, including the period when pollination occurs, so pollination difficulty may have been a cause of wild celery population loss. An additional possibility is that the floodwaters caused there to be increased sediment load throughout the year. With this increased sediment load, the irradiance may have lowered to detrimental levels. Irradiance was shown to have more of an effect on shoot biomass then sediment fertility or inorganic carbon conditions. If irradience declined, fewer rosettes may have formed on each wild celery plant. Rosettes have the potential to create winter buds, so by decreasing rosettes, the lack of light reduced winter bud formation (Korschgen et al. 1997). In fact, while wild celery can survive with as little as 5% of surface light, they need a full 9% to develop winter buds (Kimber and van der Valk, 1994). Any winter buds that were produced may have been smaller then normal, leading to weak plants that could not properly establish (Korschgen et al. 1997).

Low irradiance could have caused the plants to grow using nothing but the energy stored in the winter bud from which they sprouted. Unfortunately, if the energy in the bud is depleted, and irradience is still below the level at which respiration equals photosynthesis (~20 μmol m^{-2} s^{-1}), then the plant shoots become very brittle. The shoots may be so brittle that they may actually be destroyed by normal wave action (Rybicki and Carter, 2002).

While drought and flood events clearly diminished wild celery populations, other factors potentially contributed to the species decline as well. As early as 1980, there were losses in wild celery populations, which were suspected to be due to overgrazing by canvasbacks (Galatowitsch, personal communication). This example, paired with the flood and drought examples, show a connection between wild celery abundance and canvasback population. This connection shows that to have an increase in canvasback population, a successful wild celery restoration is a necessary prerequisite.

Wild Celery Restoration Requirements and Techniques

A truly successful restoration requires a few things, such as, the right water conditions, certain geographic locations, and temporary grazing protection. The restoration area can be secured by keeping out foraging waterfowl. Ducks, mostly canvasback ducks, have accounted for eating as much as 40% of a yearly crop of wild celery, and that was for an area that was established (Korschgen and Green, 1987). This overgrazing was clearly seen in a restoration project in the Potomac River. Waterfowl including canvasback grazed establishing vegetation, reducing planting success. However, when plants were planted inside full enclosures, (e.g. fences that completely surround the plantings) they established well and survived into future years (Carter and Rybicki, 1985 in Korschgen and Green, 1988). Korschgen and Green (1988) report that using a fence is effectively a requirement for a successful restoration. He added that adding a fence, preferably one that will remain for sometime, can not only stop predators, but might actually serve to slow water flow, increasing its chances to successfully breed.

In regards to geographic area, a restoration should be near a migrational corridor, and also in the right area for a strategic food stop. One location that fits these parameters is southern Wisconsin, where some canvasback ducks already stop. The Wisconsin Department of Natural Resources wanted to be able to accommodate 625,000 annual use days in the southeastern half of the state. To accomplish this goal, officials suggested that a restoration for wild celery should have the most success in bringing back canvasback ducks if there were 3 sites in southern Wisconsin that could have at least a total of 240 ha of wild celery. This area should be enough that 20% of canvasback duck use-days from Upper Mississippi River Pools will move to these new sites. This movement should act as a buffer against great reductions in the Canvasback population due to a disease, toxic spill, or Upper Mississippi River Pools habitat degradation.

The suggested sites for restoration in Southern Wisconsin were Lake Poygan, Butte des Marts, Koshkong, Puckaway, and Beaverdam Lakes. These lakes were selected because of their large, open water areas, which provide shelter from disturbance. Lake Poygan, which already has 335 ha of wild celery, supports 30,000 use-days in fall with its wild celery crop. This number of use days that Lake Poygan accommodates means that only two other sites now need to be restored in Southern Wisconsin (Kahl, 1991).

Extreme water conditions should be avoided to ensure a successful restoration. A large area to plant with a water depth range of 0.9-1.2 m is optimal (Korschgen and Green, 1988). This depth ensures that the water is not too deep for the female's flowers to reach the surface where they can be pollinated. An area that does have some water movement is good, but should be limited to under 0.3 m/s, above which point pollination is limited. Factors limiting pollination include the flowers being pulled under the surface of the water by the current, and the waves washing away the pollen before it can fertilize the flowers. One way to maintain beneficial velocities around your plantings is to plant in sheltered areas, as fruit set has been found to be higher in sheltered areas then in unsheltered areas. Another reason that high velocity is detrimental is the amount of sediment regularly in the water, as it can limit effectiveness of the buds, or even cause the plants to become too fragile to survive. One technique that appears to be key is to have a high density of males in your wild celery population. That technique is important because it has been shown that, even if males are placed in an optimal configuration, density of males seems to be a strong limiting factor (Sullivan and Titus, 1996).

Lake Christina, in west central Minnesota is an example of a successful restoration. Efforts began to restore the wild celery population in the lake in 1987, and they were eventually successful in regaining a population of both wild celery and canvasback ducks. The restoration was accomplished through first eliminating all fish in the lake, to restock the lake with a more appropriate amount of smaller species, such as benthivores and planktivores. These population changes caused a rise in zooplankton, macrophytes, and the lake became clearer. The increase in clarity allowed more successful growth of wild celery. The restoration was so successful that out of the over 40 former migrational stops on the upper portion of the Mississippi Flyway, only Lake Christine and four other sites still have peak populations of over 5,000 (Hohman et al. unknown date, Hanson and Butler, 1990, in Baldry, 2000).

One site that should be examined for restoration is Upper Mississippi River Pool 8. If photic depth could be raised 1%, from 100 to 150 cm, Pool 8 would see an increase in suitable wild celery area from 1379 ha to 2664 ha. To do so, suspended sediments would have to be limited to <20 mg l^{-1}. However, photic depth must not to move too far beyond the recommended depth, or the photic depth may increase by so much that other species that could push wild celery out may move into the site (Korschgen, et al. 1997).

Conclusion

To have a successful restoration of canvasback populations, wild celery populations along migratory corridors must first be restored. Unfortunately, wild celery restorations are continuing to be very difficult to do successfully. The difficulty exists mainly because there continues to be very poor water quality in the Upper Mississippi River for a few reasons. Boat traffic continues to be heavy in the area, churning up sediment, decreasing water clarity. Also, water pollution is a problem that is still affecting the system on a landscape scale. Pollution needs radically reduced throughout the Upper Mississippi River watershed. However, while a complete restoration may not be feasible, small restorations that are carefully cared for can be successful in stabilizing the wild celery and canvasback duck populations for years to come.

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