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Bowfishing in the United States: History, status, ecological impact, and a need for management

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In this paper we review the history and development of bowfishing, provide a case study of a high-profile bowfishing tournament in Oklahoma, survey and summarize management of the sport in all 50 states, and provide scientifically-based approaches for its management. Bowfishing has a distinct niche in the evolution of the bow and arrow and in fishing, as one of several methods practiced by many and scattered indigenous cultures worldwide. In the past century, advances in technology, including the development of the compound bow, custom boat and lighting systems for night bowfishing, and improved information transfer have opened the sport to many people previously unable to participate in the sport at a satisfying level. Bowfishing poses some distinct challenges for fisheries managers compared to angling, including the impracticality of catch-and-release, non-catch (wounding) mortality, and by-catch mortality of non-targeted native species. In 2019, we conducted a survey of 50 state fish and wildlife agencies that indicated only nine states had bowfishing education programs and none had articulated management goals or plans specific to the sport. Evidence indicates that bowfishing may provide plentiful opportunities for harvesting nuisance invasive species such as Asian carps (Cyprinidae) and the Common Carp *Cyprinus carpio*, but must be practiced much more judiciously, and in some instances, not at all, depending on locality, for higher valued native species such as buffalofishes (Catostomidae: *Ictiobus* spp.), Paddlefish *Polyodon spathula*, gars (Lepisosteidae), and rays (Batoidea). Whereas in the terrestrial and avian species that bowhunters most commonly target, males reach a larger size than females, in fish species targeted by bowfishers, the opposite is the case. The result is selective depletion of large, older, mature females and evolutionarily disruptive truncation of life histories. We suggest ten of many potential topics for consideration in agency management planning for bowfisheries. We seek to provide agencies information for developing historical, ecological, and socioeconomic perspectives for managing bowfisheries, as other fisheries, as instruments of species conservation, public benefit, and sound long-term public policy.

Keywords: fisheries management, gars, Asian Carp, buffalofishes, Paddlefish, archery, bow and arrow

Introduction

Whether you are a beginning, intermediate, or even advanced archer, archery will give you something that's almost impossible to find elsewhere. – USA Archery

"[Archery] a sport which is as harmless and fascinating as it is old and honorable" – Maurice Thompson (1878, p. 1) *The Witchery of Archery.*

Every aspect of human technology has a dark side, including the bow and arrow. – Margaret Atwood

What are we looking for? Basically, any trash fish that will swim, but the main target today is gonna be some gars… – Relentless Anglin' (2017)

Figure 1. Bowfishing from a custom-designed boat equipped with flood lights, trolling motor, and raised platform for night bowfishing. Note the fourth bow on deck and the large stock tank in the image foreground used as a receptacle for shot fish that are landed. Image courtesy of Zach Kjos, North Dakota Game and Fish Department.

Bowfishing, the taking of fish with a bow and arrow, or a crossbow, is a specialized sport gaining interest and participation in both fresh and marine waters. It is one of the fastest growing segments of archery sports in the United States (Woody 2019). As one aficionado described it, "for as little as $20.00 you can get a drum reel and an arrow. You can shoot from shore or a boat. Day or night. Alone or with some friends. You can target Common Carp to alligators and stingrays." (Appleberg 2006). With the expanded interest in bowfishing has come major expansion in the technology of bowfishing gears (Fig. 1), a proliferation of bowfishing tournaments with large cash prizes, and professional associations dedicated to the sport. The tournaments, by "combining the challenge of bow fishing with the spirit of competition, … can be as fun or as serious as you want to make it... Tournaments can range from a couple of hours to days. The longer tournaments are often described as 'Ironman'

tourneys. Indeed, you have to be tough as nails to shoot for 24 hours straight. It's the archery version of an extreme sport." (Appleberg 2006).

Several factors have influenced the growth of bowfishing. Ecological changes have also contributed to the increasing national and regional interest and participation in bowfishing. Dam construction throughout the United States has concentrated pre-spawning fish in areas such as clear tailwaters especially amenable to bowfishing (Mestl et al. 2019). More shallow, lentic habitat in bays has also resulted from dam construction and reservoir impoundment, where fish can be more easily seen and shot with a bow and arrow. Species such as gars (Lepisosteidae), which inhabit shallow spawning areas in spring and summer (Allen et al. 2020), where they often bask (Potter 1927) and gulp air during oxygen-depleted times (McCormack 1967), can be especially vulnerable to bowfishing. Another factor has been the increase throughout much of the United States of nonnative fish, including the Common Carp *Cyprinus carpio*, Grass Carp *Ctenopharyngodon idella* and other invasive Asian carps (Cyprinidae: Bighead Carp *Hypophthalmichthys nobilis,* Silver Carp *H. molitrix,* Black Carp *Mylopharyngodon piceus*; Hinterthuer (2012)).

Improved archery technology since the 1970s, including the invention of the compound bow (Allen 1969; Robb 2018), has opened the sport to archery achievements by many men, women, and children unable to handle longbows and recurve bows to their satisfaction. Custom boats with raised decks and elaborate lighting systems for night use are now designed and equipped specifically for bowfishing (Fig. 1). Increased access to bowfishing information from diverse media outlets has provided bowfishers an opportunity to become informed faster than has ever been possible. Technological advances such as cell phones and GPS devices have increased the efficiency and responsiveness of fishers (e.g., Cachon et al. 2015).

Bowfishing also affords greater opportunity to shoot, kill, and maim, often without making use of the fish, than is typical in most bowhunting. Liberal or no bag limits for bowfishing nuisance species such as the invasive carps allow much more opportunity for take than does bowhunting large terrestrial game species such as deer or elk. Bowfishing is seen by some as providing a service to anglers. With the increase in recreational and tournament angler (i.e., hook and line) interest in specific game species such as the basses (e.g., Largemouth Bass *Micropterus salmoides*) has come a desire to reduce other native species not viewed favorably by most anglers but found to be removable with bowfishing. Such species include gars, Bowfin *Amia calva*, suckers and buffalofishes (Catostomidae), and, in marine habitats, rays (Batoidea).

Other factors contributing to the increased participation in bowfishing may be rooted in human psychology, mental control, and spiritual training (Haywood 2006). A sampling of social media (text and video) quickly displays the passion with which many bowfishers pursue their hobby. Archery has been recognized as a skill sport in which both hits and near misses fuel the illusion of control, potentially leading to the compulsive desire to continue participating (Clark 2014). The potentially compulsive aspects of the sport have been described, often with an almost religious fervor, by adherents. The German philosophy professor, Eugen Herrigel, studied Japanese archery (kyūdō) in his exploration of Zen (Herrigel 1953). Archery is seen as a source of mental discipline and control (Shōji 2001). As Zen scholar D. T. Suzuki introduced Herrigel's (1953) book: "In the case of archery, the hitter and the hit are no longer two opposing objects, but are one reality" (p. viii). The practice, control and focus required in archery has also been recognized and applied as therapeutic for various life stressors, including post-traumatic stress disorder (Bryan et al. 2018; The Ranch Tennessee 2020).

Bowfishing is practiced on a variety of species of widely different perceived value to society: invasive species such as the nonnative Common Carp and Asian carps (Bajer et al. 2016; Phelps et al. 2017), native, historically underutilized but now often declining species such as buffalofishes (*Ictiobus* spp.; Solomon et al. 2016), native predators such as gars of substantial ecological value (Scarnecchia 1992; Bennett et al. 2015) but disfavored by many sport anglers, and species with a complex identity such as the Paddlefish *Polyodon spathula*, that are taken by bowfishers in some states but protected in other states (Quinn 2010; Mestl et al. 2019). Non-piscine aquatic species taken by bowfishers that are not specifically considered here include the American bullfrog *Lithobates catesbeianus*, American alligator *Alligator mississippiensis,* and several species of turtles.

The sport of bowfishing poses some distinct challenges for fisheries managers compared to other types of fishing. For example, catch-and-release for more valued species is not a viable option (e.g., Paddlefish snagging: Scarnecchia and Stewart 1997). In that sense, the sport is more accurately described as aquatic bowhunting. Non-take mortality from wounding needs to be considered more so than in most other types of recreational fishing. This problem is worsened because preferential, selective removal of females is more likely in bowfishing than in typical bowhunting for terrestrial species such as deer or elk. Unlike terrestrial species, where the mating systems often favor larger males than females, the vast majority of North American freshwater fish species, including essentially all of the common species bowfished, have mating systems favoring larger females (and their higher fecundity) than males, with females maturing later in life (Bell 1980; Scarnecchia et al. 2007; Koch et al. 2009; Daugherty et al. 2019; Lackmann et al. 2019). Because larger fish may be easier to see and hit, the tendency to kill or maim the large females may be greater than in hook and line fishing (i.e., angling). Many of the species are also longer-lived than most terrestrial quarry (Bell 1980; Scarnecchia et al. 2014; Daugherty et al. 2019, 2020; Lackmann et al. 2019). A size and age bias and resulting truncated age structure can create unnatural selection pressures and evolutionary responses in a fish stock (Kuparinen and Merilä 2007) that some managers try to avoid (Francis et al. 2007; Scarnecchia et al. 2014). Another issue is that in areas where several species intermingle, by-catch and mis-identification mortality of native species of concern can be a major problem. Other fishery management concerns about bowfishing are similar, but no less important, than for angling. Yet compared to terrestrial bowhunting, where management has become more conscientious and oriented toward sustainability, most bowfishing is pursued in an environment of high or no bag limits and few or non-existent special licensing or permitting requirements. On the positive side, however, bowfishing has been used by fisheries biologists in a few instances as a fish sampling method in situations where survival of the sampled fish has not been considered an issue (e.g., Tyler and Granger 1984; Morrow et al. 1997).

More information is needed about the relationships among bowfishers, anglers, and the public. Longmire (2012) polled South Dakota anglers for potential conflicts with bowfishers and found that 91% of the respondents perceived no bowfishing conflicts with hook and line fishing. As the sport expands, the potential for conflicts may arise, both in overlapping fishing space and in situations where anglers and bowfishers might be pursuing or incidentally killing the same desirable species. Other conflicts are arising as night bowfishing becomes more popular. Bright lights from bowfishing boats across open expanses of water at night can directly or reflectively penetrate windows or porches of lake and river-side dwellings, leading to disruptions and conflicts with residents (Farkas 2020).

The challenge for managers, and the focus of this paper, is how to effectively and sustainably manage this sport for the long-term benefit of the fish communities, species and society, consistent with diverse management goals for native and nonnative species. Although our review of websites indicates that the sport of bowfishing is clearly in an expansion phase, the dearth of scientific studies on bowfishing (an exception being Quinn (2010)) suggests that conceptualization of how these fisheries should be managed and monitored has lagged well behind the fisheries themselves in many localities. Some fisheries managers undoubtedly have knowledge and experience with bowfishing and bowfisheries, whereas others have little or no knowledge of the sport. Background knowledge of the sport should prove useful for many fisheries managers.

We designed this paper to be a thorough and up-to-date review of the history, development, status, and current and future management needs of bowfishing in the United States. We provide a case study of a high-profile bowfishing tournament in Oklahoma, survey and summarize state management of bowfishing in the 50 states, and provide information for a framework for understanding and proactively managing the sport. We aim to provide agency managers and others involved with the sport a solid grounding for guiding their management actions and their interactions with bowfishers in the field and at tournaments. We seek to aid agencies in developing historical, ecological and socioeconomic perspectives for managing bowfisheries, as other fisheries, as instruments of species conservation, public benefit, and sound long-term public policy.

This paper consists of seven sections: 1) this introduction; 2) origins and early history; 3) modern technological advances in bowfishing; 4) sport governance and tournaments; 5) a case study of the 2018 U. S. Open bowfishing tournament; 6) national status and regulation in the 50 states; and 7) science-based approaches for management. Fishery managers and administrators largely unfamiliar with archery and bowfishing may benefit from all sections. Managers of Native American fisheries may find Sections 2 and 7 of particular interest. Those interested in technological aspects of archery and bowfishing will benefit from Section 3. Fisheries administrators may benefit most from Sections 4-6. Agency managers already knowledgeable of bowfishing and tournaments (i.e., Sections 1-6) can focus on Section 7, where results of ecological and life history research studies are synthesized into specific recommendations for management of bowfisheries, and where ten topics for future management planning are provided.

Origins and Early History of Bowfishing

> *"The Choctaws and Chickasaws seldom if ever fish with a rod and line. They prefer the bow and arrow, with which weapon, when the water is low and clear, they frequently procure the largest fish. At certain times the Indians get together for a grand "fry". By means of a weed called "Devil's Shoe String", which they chop or beat up and throw into the water, they stupify and intoxicate the fish in such a manner as to be able to secure all that they require for present use. The weed, however, is not deadly poison, its effects being but temporary"* (O'Beirne 1891, p. 211)

The bow and arrow have a long history, both as weaponry in intergroup warfare in Asia, Europe, and North America (Maschner and Mason 2013) and in hunting and fishing for food (Laubin and Laubin 1980; Tomka 2013). Their use sometimes occurred in conjunction with poisoned arrowheads (Bradley 1956; Jones 2007; Robbins et al. 2012; Langley et al. 2020).

The exact origin of the bow and arrow remains uncertain and is an area of active research. Recent studies provide fragmentary and inferential evidence of its origins in southern

Africa 60,000-64,000 yr BP (Sibudu Cave, South Africa: Lombard and Phillipson 2010; Backwell et al. 2018). Evidence for bow and arrow use is also suggested from the Kalahari (Botswana), 35,000-45,000 yr BP (Robbins et al. 2012). Earliest indications suggesting bow and arrow use outside of Africa are from the Fa-Hien Lina Site in Sri Lanka, 48,000 yr BP (Langley et al. 2020). Pictures on the walls of caves in what are now France, Spain, and Egypt attest to the use of bows in the Upper Paleolithic period (ca. 40,000 yr BP; Znamieroska-Prüffer 1966). Shōji (2001) reported that archaeological sites in Japan showed evidence of the bow and arrow from about 7,000 yr BP. In North America, the bow and arrows are thought to have originated from Asia (Laubin and Laubin 1980). Some experts see that movement primarily through a more recent, broad diffusion (Blitz 1988) whereas others have favored an older, somewhat less-diffusive pattern and more independent inventions of the technology. (e.g. Arkansas; Nassaney and Pyle 1999). Maschner and Mason (2013) reported on the presence of at least four waves of introduction of the bow and arrow into the region now known as Alaska, the first as early as 12,000 yr BP. It evidently disappeared from use by 3,500 yr BP, but by 1,200 yr BP it was being used in the Alaskan interior. No matter how many times the bow and arrow were invented independently or reintroduced, the technology diffused widely from the Arctic region, east and south (Taylor 2001; Tomka 2013). By the time of European explorers' encounters with native tribes, the bow and arrow were in use throughout North, Central, and South America (Rogers 1940; Laubin and Laubin 1980).

The crossbow, a bow and arrow with the addition of a stock and a string-catch, took a different path to North America. Wilbur (1937) provides a succinct review of its origins. It was first described in China twenty-four centuries ago (Payne-Gallwey, 1903). It was used as weaponry by the Chinese, later by the Romans in the fifth century, and developed greatly in design and application in Europe during the Middle Ages. It was introduced into England during the Norman conquest and later used effectively by Spaniards in conquests of the New World (Arnold et al. 1995). It appears to have come to North American from the east, from Europe and also from western equatorial Africa (Powell-Cotton 1929), where it had been introduced by Europeans, later adopted by native tribes, and brought to the Americas via enslaved populations (Ball 1996). Its subsequent use by the Rappahannock Tribe (Virginia: Hassrick and Carpenter 1944) and Catawba Tribe (South Carolina: Speck 1946) are thought to have African origins. Modern improvements are described at Crossbowmen.com (2020).

Bowfishing has a distinct, if narrow, niche in the evolution of the bow and arrow and in fishing. Radcliffe (1921, p.40) postulated that the first fishing was by hand, and … "Third comes fishing with a line of some sort." In between these forms—i.e., the second form--was "by spear, and then the spear harpoon, with barbs on one side, where the barbed head could come free of the shaft, to where… we ultimately attain … an arrow shaped like a trident shot from but attached to a bow." (ibid., p. 40). The bow and arrow as a fishing gear can thus be characterized as having evolved from earlier thrusting and piercing weapons and implements such as the spear, javelin, atlatl (e.g., for throwing darts; Aleuts: Orchard 2001), and harpoon (Mason 1902; Znamieroska-Prüffer 1966; Taylor 2001). Intermediate development stages between spear and bow and arrow (e.g. harpoons, atlatl, and modifications), including detachable points (Ojibwa First Nation: Parry Island, Canada, Jenness 1935; Makah Tribe: Hoko River Site, Washington, Croes and Blinman 1980) are well-described (e.g., North America: Mason 1902, Laycock 1990). Rau (1884, p. 152-153) described a unilateral barbed copper dart head (i.e., barbed on one side) from Wisconsin: "Those like it … are now used in Tierra del Fuego. Meeting with unequal resistance in the water, it will not go straight. So it seems an absurd pattern, but it is found that if

aimed at a fish it will hit him, for owing to the refraction of light, he is not where he looks as if he were. One barb is then better than two, and we are the fools after all."

An advantage of the bow and arrow compared to other thrusting implements was that the small size of arrows made it easier to carry more of them. Other benefits of the bow and arrow over the spear included more rapid velocity and, with training, better accuracy (Bettinger 2013). Arrowheads required less flint than spear heads (Weitzel 2018). Bowfishing required additional training and skill, however, in part because of more extreme refraction of water when shooting at an angle from a distance.

Materials used for construction of early archery equipment varied. Bows could be made from bone (e.g., elk ribs) and horn (bighorn sheep, bison) and woods that would flex without breaking, including ash, hickory, locust, Osage orange, cedar, juniper, oak, walnut, birch, chokecherry, yew, and others. Hamilton (1982) and Weitzel (2018) described three kinds of bows: self bows of a single stave of wood, backed bows with sinew reinforcement, and composite bows with wood, horn or antler, and sinew backing. Tomka (2013) describes sinew-backed bows and composite bows as having a greater draw weight (penetrating force) than self bows. Bowstring could be made of plaited or twisted plant fiber, leather, or cotton. Arrowheads were of bone, horn, or flint and were often replaced later by metals such as bronze and iron. Arrows were made of various woods (Znamieroska-Prüffer 1966; Laubin and Laubin 1980), including ash, birch, wild rose and chokecherry in North America (Weitzel 2018). Wilbur (1937) discusses a range of historical technological advances in the crossbow up to that time.

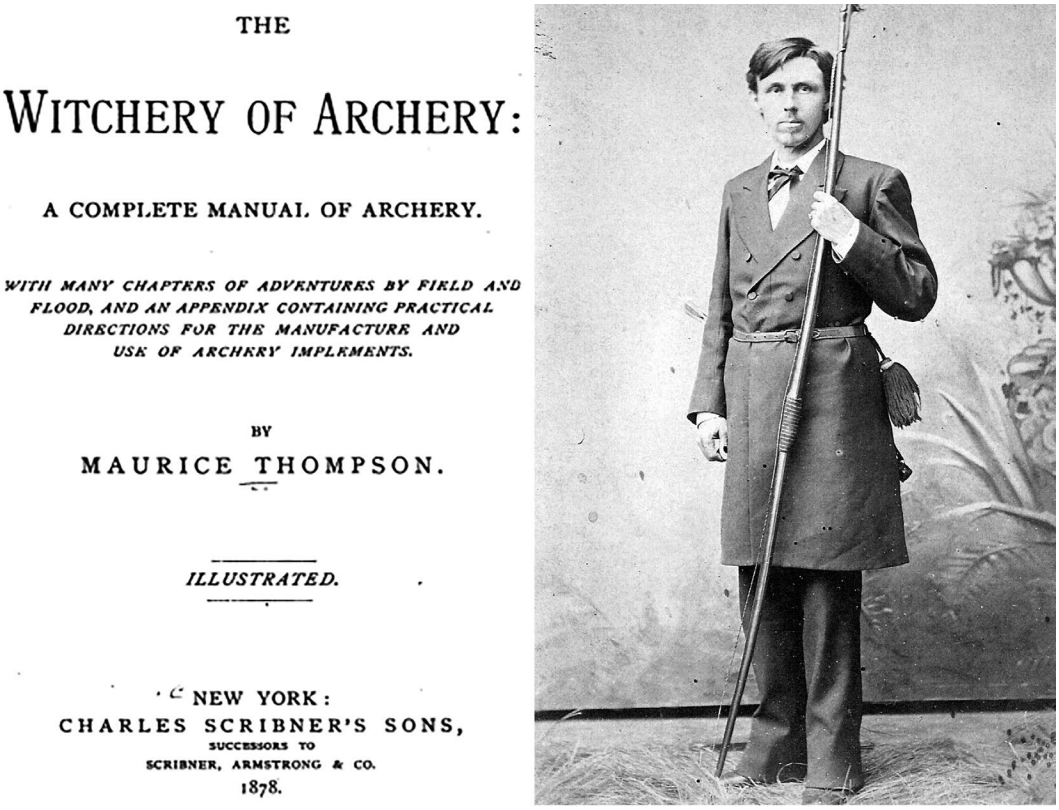
Early evidence of bowfishing comes from archaeological sites, early writings, illustrations, and direct ethnological observations (e.g., Rau 1884; Rostlund 1952). Waterman (1975) notes that it is often impossible to tell whether ancient spears and arrow points were used for hunting, fishing, or both. Rau (1884) and Rostlund (1952) summarized available reports of aboriginal bowfishing in North America based on writings mostly of the sixteenth through nineteenth centuries. Bowfishing was often used as training and preparation for hunting and warfare. Rau (1884) cited Loskiel (1794) writing on the Delaware and Iroquois tribes, where "Little boys are even frequently seen wading in shallow brooks, shooting small fishes with their bows and arrows" (p. 283). He also cited Lawson (1714) on indigenous people of North Carolina, where, "…the youth and *Indian* [his italics] boys go in the Night, and one holding a Lighted Torch, the other has a Bow and Arrow, and the Fire directing him to see the Fish, he shoots them with the Arrows, and thus they kill a great many of the smaller fry and sometimes pretty large ones." (p. 290). These and other reports from North America (e.g., Flatheads, Montana: Ronan 1890; Eyaks, Alaska: Birket-Smith and De Laguna 1938; Osages, Missouri: Tixier 1940; several other tribes: Rostlund 1952) indicate that the practical value of the bow and arrow in North America often first developed with children and youths as a training tool, for recreation, or both (Mason 1893).

Rau (1884) and Rostlund (1952) also summarized observations of tribal bowfishing practiced by adults. As quoted in Rau's (1884, p. 288) review, Captain John Smith (1624) wrote that "they [Indians of Virginia] use long arrows tied in a line, wherewith they shoot at fish in the rivers." In Histoire de la Louisiane, Du Pratz (1758, also cited in Swanton 1911) recorded that "They [native peoples] sometimes make arrows of thin, hard canes, but these only serve for shooting birds and fishes…. Their war arrows are usually armed with a scale of the bony gar fish (Poisson-armé); but if their arrows are designed for shooting carp or cat-fish ("*Barbue"*), which are large fishes, they attach to the shaft a bone pointed at both ends in such a manner that one end forms the point of the arrow, while the other is a little distant from the shaft, which prevents

the arrow from coming out of the body of the fish. The arrow, moreover, is connected by a string with a piece of wood, which floats and does not allow the fish to go to the bottom or to escape." (p. 293). Speck (1930; 1946) described bowfishing for carps and suckers in the early twentieth century among the Catawba Tribe of South Carolina. Rostlund (1952) compiled the scattered historical reports of bowfishing among tribes, including several from the southeast (e.g., Cherokee, Choctaw, Creek (Swanton 1946), and Seminole (MacCauley 1887)). After the removal of the southeastern tribes to Indian Territory (Oklahoma), Choctaws and Chickasaws were described by O'Beirne (1891) and Creeks described by Debo (1941) as using bowfishing in combination with Devil's shoe-string [Fabaceae: goat-rue, *Tephrosia virginiana*], a native source of rotenone, as a fish toxicant (Krumholz 1948) to obtain fish for subsistence. American artist Seth Eastman's painting entitled *Indian Shooting Fish* depicted bowfishing as practiced by tribes in the Great Lakes region (Dakota (Santee Sioux) and/or Ojibwa) and illustrated Henry Schoolcraft's authoritative tome on Native American tribes (Schoolcraft 1852). In Rostlund's (1952) review of tribal fishing methods, it was noteworthy that many other tribes he investigated did not seem to practice bowfishing, even over large areas (Northwest Coast, much of Prairie and Plains), instead favoring other types of food or other more effective methods of fishing in their areas such as nets, traps, hooks, and spears. Some tribes even had taboos against it.

Those North American tribes that did use bowfishing seemed to use it, as they used bowhunting, for several purposes: as a source of food (e.g., Smith 2010; Fig. 2), for hunting and warfare skills (Cummins 2003), and for recreation. Other, international studies of past and present indigenous bowfishing are not reviewed here (e.g., Andaman Islands: Ganguly and Pal 1962, Bednarik and Sreenathan 2012; New Guinea: Dosedla 1984, Lokoloko 2004, Quinn 2004, Sibange 2004; Solomon Islands, eastern Europe (Hungary): Znamieroska-Prüffer 1966; Venezuela: Gragson 1992, Greaves 1997). In both North America and Europe, as firearms replaced the bow and arrow as weaponry and hunting tools in the eighteenth and nineteenth centuries (Mason 1893; Laubin and Laubin 1980; Taylor 2001), there was less of a need for skills in archery. As of 1957, Znamieroska-Prüffer (1966) noted that "… the bow ... has changed in Europe from a hunting into a sporting weapon, is no longer used for fishing, and is only treated as a tradition" (p. 151). It nevertheless maintained its cachet among the fashionable upper-class men and women (Koppedrayer 2004). In addition to its social function, it satisfied a fascination with medievalism and a perceived return

Figure 2. Sam Resurrection, Salish Tribe, bowfishing, most likely for Bull Trout *Salvelinus confluentus*, on the Clark Fork River, Montana. ca. 1915. Sam (1857-1942), according to Salish Lore, was once thought to have died as a youth but was "resurrected" and monikered with that English surname. He went on to play an important role in influencing treaty rights on and around the Flathead Reservation (Stromnes 1999). Image courtesy of University of Montana Library.



THE

WITCHERY OF ARCHERY:

A COMPLETE MANUAL OF ARCHERY.

WITH MANY CHAPTERS OF ADVENTURES BY FIELD AND FLOOD, AND AN APPENDIX CONTAINING PRACTICAL DIRECTIONS FOR THE MANUFACTURE AND USE OF ARCHERY IMPLEMENTS.

BY

MAURICE THOMPSON.

ILLUSTRATED.

NEW YORK:
CHARLES SCRIBNER'S SONS,
SUCCESSORS TO
SCRIBNER, ARMSTRONG & CO.
1878.

Figure 3. The Witchery of Archery by Renaissance Man Maurice Thompson fervently depicted mythological, romantic, adventurous, and practical aspects of archery.

to a simpler, pre-industrial time (Johnes 2004). The skill-building and recreational aspects of aboriginal and European-American bowfishing in North America have retained their importance in modern, technologically advanced bowfishing and competitive tournaments in the United States.

Sport bowfishing's recent evolution, technological advances, and participation in the United States

In many respects, modern bowfishing development in the United States parallels the overall evolution of the sport of bowhunting. In an obscure guidebook (i.e., "Vade Mecum") for American archers, Elmer (1917) describes early twentieth century archery as influenced by diverse sources, including indigenous, European, African, and Asian. Mogren (2013) traced aspects of the development of modern bowhunting starting from the nineteenth century with "romantic bowhunting stories written by brothers Maurice and Will Thompson in mass circulation magazines, including *Appleton's Journal*, *Harper's Magazine*, and *Scribner's Monthly*, during the 1870s" (p.219). Maurice Thompson's book *The Witchery of Archery* (1878) became a popular source of exciting stories and practical information that expanded interest in the sport. Archery is explored in all of its mythological, romantic, adventurous, and practical aspects by Thompson, a Renaissance Man with expertise in law, natural history, civil engineering, literature, and poetry (Fig. 3). His brother Will was a champion archer. These and other writings increased interest into the early twentieth century. In 1923, Saxton Pope, a clinical professor of surgery in California, wrote *Hunting with the Bow and Arrow* (1923a),

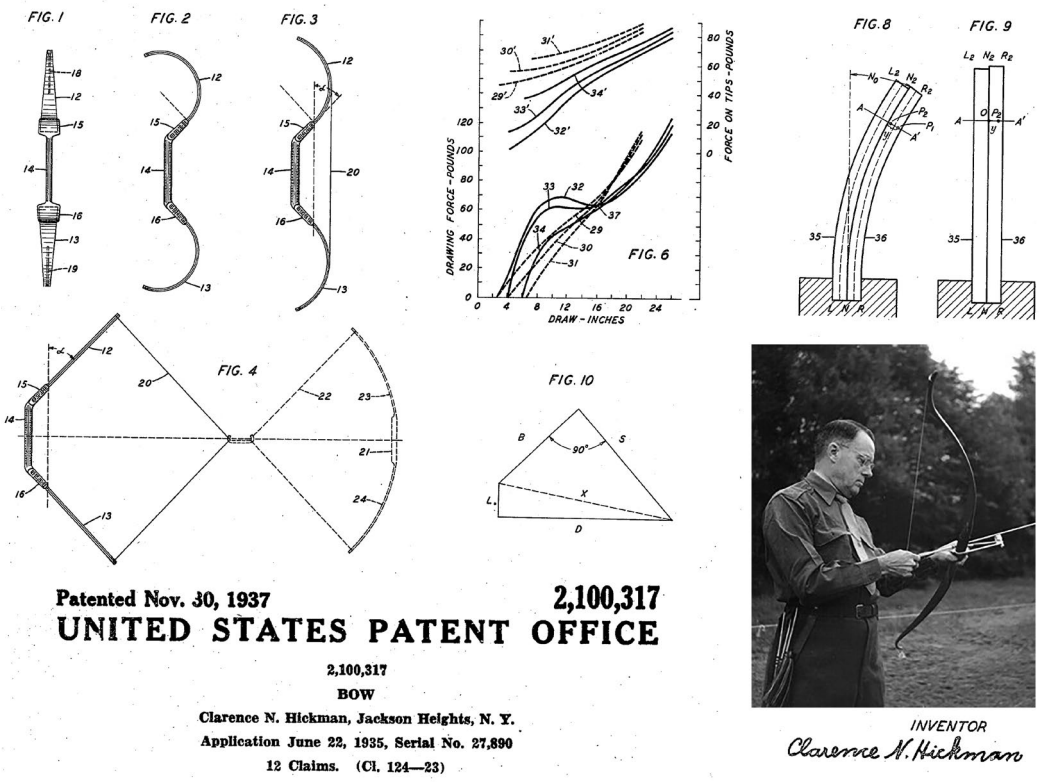


Figure 4. Clarence Hickman, often called the father of scientific archery, used his background in physics to develop and patent a recurve bow with a mechanical advantage over the traditional longbow. Bracing a bow resulted in an additional advantage over an unbraced recurve bow. From Hickman (1937a).

another popular account of archery, in which he discussed not only numerous adventures in hunting, but his encounters with Ishi, the Yahi (Yana) Indian who introduced him and others to archery as practiced by his vanishing tribe (Pope 1918; Kroeber 1927; Kroeber 1961; Edinborough 2005). Pope also wrote *A study of Bows and Arrows* (1923b), a quasi-technical review of different equipment known from around the globe at that time. From these early influential writings and subsequent archery journals and popular magazines targeting both men and women bowhunters and bowfishers, information, knowledge and interest proliferated through the mid- and late- twentieth century (Amada Archery 1958; Mogren 2013).

Gears and Technologies - In understanding the evolution of bowfishing into a modern sport, advancements in gear and technology provide one indicator. One way of identifying and recognizing technological advances and commercial development is through inspection of United States patents. Schumm (1983) discusses the contributions of Clarence Hickman, another Renaissance Man and inventor, with a strong physics background, who made numerous contributions in physics, weaponry (Fig. 4), and in technical aspects of archery equipment. Characterized by Schumm (1983) as "the father of scientific archery" (p. 1) and the man who transformed archery from an art to a science, his physical injuries and ailments (and slight build) may have further inspired him to improve the efficiency and

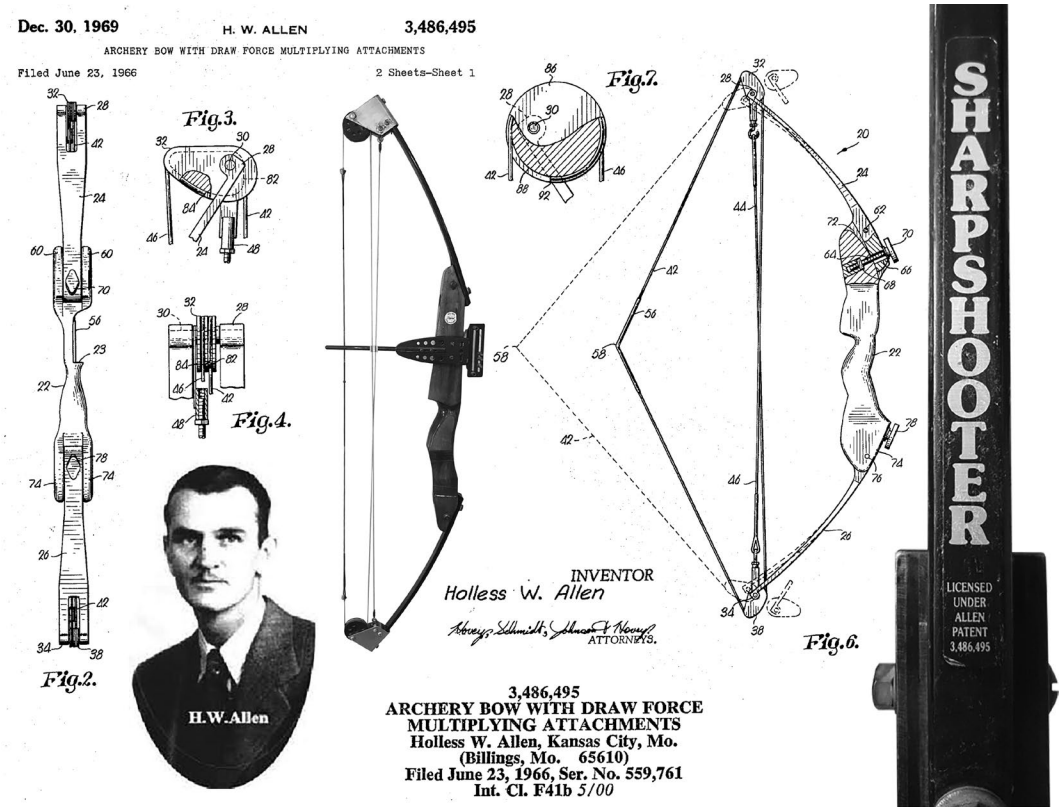


Figure 5. With the development of the compound bow by H. W. Allen, the resulting user-friendly design opened the sport of archery to a much higher percentage of the entire public. Inset photos by L. F. Ryckman, Bismarck, North Dakota. Diagrams from Allen (1969).

practicability of the sport. His research into a recurve bow, a concept long known and used but not theretofore technically explained to that extent, was described fully in terms of dynamics (i.e., the branch of classical mechanics concerned with the movement of objects under forces) in his patent application and in a related article (Hickman 1937a,b; Fig. 4). His work led to further development by physicists in understanding the dynamics and ballistics of recurve bows (Klopsteg 1943; Schuster 1969). A lesser-known Hickman patent concerned the process of applying silk as backing for the bows, one of numerous attempts by inventors to improve the resiliency of the bow and prevent it from "taking a set", or becoming permanently bent, under repeated use (Hickman 1942). Other inventions to improve resiliency and reduce the length required of a bow include Pikula's (1961) patent to offset the handle of the bow away from the archer (i.e., with the arms toward the archer) and sportsman and conservationist Frederick (Fred) Bear's patents using composite and fiberglass reinforced materials to improve bow strength and prevent it from taking a set (Bear 1952, 1954).

Although the foregoing patents described improvements over Ishi's mountain juniper longbow (Pope 1918), for modern bowfishing, the most important technological advance in the past millennium was probably the invention in the late 1960s (and later patent in 1969) of the compound bow by the little-known inventor Holless Wilbur Allen of Billings, Missouri (Fig. 5). The idea of having wheels on a bow was not new; nearly a century earlier, for example,

Howe (1882, p. 1) patented a ratchet and pawl system at the ends of a bow "by means of which the tension of the bow cord may be increased or reduced at the will of the archer without unstringing the bow or loosening the bow-cord". In the 1960s, Allen experimented with sawing off the ends of a recurve bow and attaching a block and tackle system. As described in a litigation document, "the compound bow system covered by Allen's patent employs rotatable pulleys or cams and multiple line lacing of the bowstring or cable to create compound leverage". The important advantage of the compound bow, as opposed to more conventional bows, is that [it] casts the arrow at greater speed with increased striking power while reducing the amount of force needed to draw the bow. … Within eight years of obtaining the patent, Allen had licensed virtually the entire industry" (p. 2) (Allen Archery 1989). According to Robb (2018, p. 3), "By 1976 all states except Georgia legalized their use during bowhunting seasons. About this time the Pope & Young Club [a conservation and bowhunting organization that keeps records of trophy animals] began accepting entries taken with compound bows… It took less than 10 years for the compound bow to become the dominant force in all of archery". Although the compound bow offered many advantages, including better consistency and accuracy and assembly line manufacturing, the most significant advancement was that its improved mechanical advantage opened the sport to many men, women, children, and many physically challenged individuals not previously capable of practicing archery at a successful and satisfying level. The sport was no longer necessarily dominated by the exceptionally strong or fit but could be practiced and enjoyed by a much larger fraction of the population.

Technological advances have continued into this century. Using the Google® Patent Search function (patents.google.com; access date July 10, 2019) for the term "bowfishing", we observed an increase in patents filed during the period 2010-2018 (Fig. 6) with a peak of 15 applications in 2014. These modern advances span a broad spectrum of technologies and applications, from laser bow sights to efficient and rapid retrieval mechanisms to custom designed watercraft with generators, abundant lighting, and hulls designed for more effective bowfishing in shallow water. As is typical in such developments in fishing gear, these advances in technology were generally aimed at increasing the accuracy, efficiency, and thereby the enjoyment and satisfaction of bowfishers. In particular, improvements in lighting systems have led to and coincided with increases in night fishing, including its recent legalization in some locations (e.g. 2010 in Minnesota). With improved lighting technology, night bowfishing favors bowfishers in several ways over day bowfishing: 1) there is less water disturbance at night because of less activity of the general public; 2) there is reduced glare from the sun and clouds, resulting in greater prey visibility; 3) there is typically less wind at night, so that the calmer waters increase prey visibility at a given depth; 4) some fish species are more vulnerable at night because they may be less active, may move into shallower water, and are often less skittish; 5) bowfishers can "shine" fish with their lights against the dark backdrop of night and in many cases fish will sit motionless as they appear to be stunned, and 6) enforcement of regulations is typically more of a challenge for agencies at night. Although much more study is needed in all of these areas, the limited available evidence reviewed in Cooke et al. (2017) supports these conclusions.

Some of the recent technologies are expensive, but success for the entry-level bowfisher does not require a substantial investment. Off-the-shelf bowfishing bows (with reel and arrows) can be purchased online or at sporting goods retailers nationwide for less than $300. Retro-fit kits for any bow are available for less than $150. McDougal (2017) interviewed three retailers of bowfishing equipment regarding the popularity of bowfishing and the equipment required for the sport. All three retailers conveyed that the retail market remained small but was growing. While entry-level bowfishers can get by with a terrestrial hunting

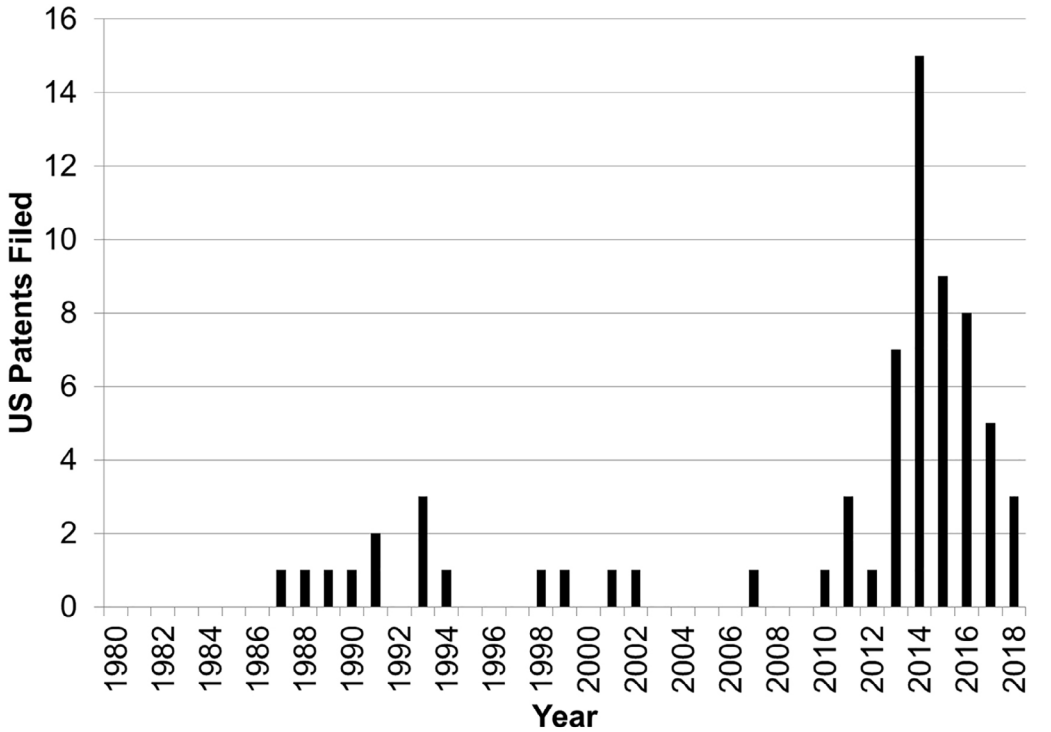


Figure 6. United States bowfishing patent applications (n=67) filed for the period 1980-2018. Results are from a search for "bowfishing" on patents.google.com (Accessed July 10, 2019).

bow retrofitted for fishing, more dedicated, longer-term adherents will typically upgrade to purpose-built bowfishing equipment. The retailers noted efficiency (i.e.,"snap-shooting" in bowfishing versus a high-letoff compound bow for hunting), convenience (i.e. maintaining separate, dedicated archery equipment for hunting and fishing), and safety (i.e., failure or breakage of high-powered bowhunting equipment when used for bowfishing) as the three primary reasons for bowfishers buying purpose-built bowfishing equipment.

Participation – No thorough analyses of bowfishing growth and participation have been performed to date. The most representative data may come from the Archery Trade Association (ATA), which has examined growth in archery participation in general, including target archery, bowhunting, and bowfishing, over the period 2012-2015 (ATA 2016). Overall, participation in archery had increased by 24% from 2012 to 2015, with increases in all regions of the United States (Northeast, Midwest, South, and West). The region with highest 2015 increase in participation overall was the Midwest, with 12% of respondents participating in archery. However, the 2012-2015 total growth of archery participation in the Midwest (9%) was slower than that of the South (36%), West (31%), and Northeast (14%), suggesting that the other regions were catching up in archery interest and participation. The report also examined demographics and regional trends in bowhunting specifically in more detail. While participation in bowhunting was observed to be relatively consistent in the Northeast, Midwest, and West between 2012 and 2015, a 129% increase in participation was observed for the South. Further, 42% of survey respondents who participated in bowhunting lived in the South. Despite these statistics, the report notes that respondents from the Midwest and South were similar in respect to bowhunting participation while the Northeast and West regions were similar.

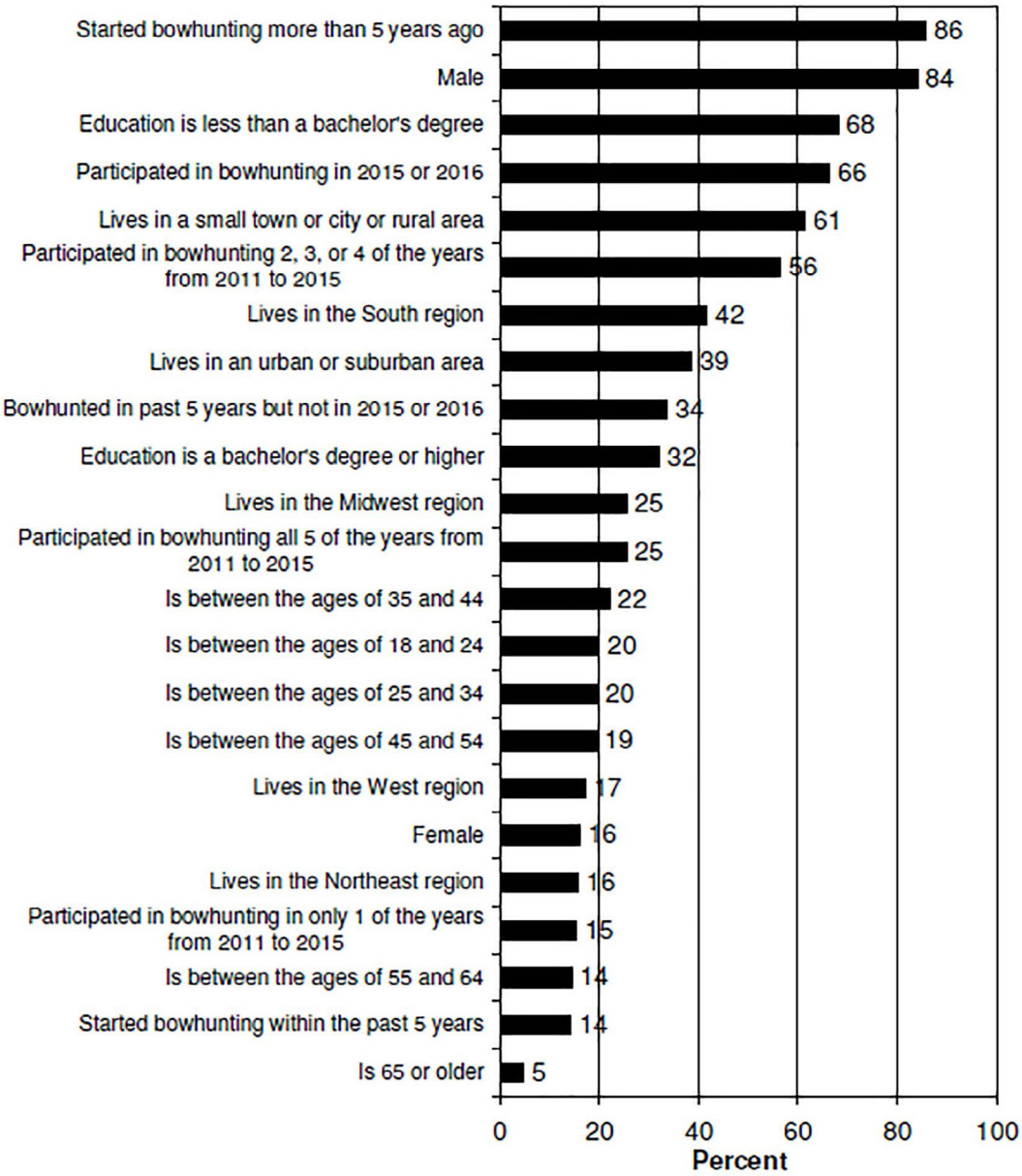


Figure 7. Profile of a bowhunter, reproduced from ATA (2016). Values represent percent of survey respondents who bowhunted during 2011-2016

The report also provided demographic information and described a "Profile of a Bowhunter" (ATA 2016; Fig. 7). A large majority of bowhunters were male (84%) with education less than a bachelor's degree (68%) and living in a small town or rural area (61%). Age of bowhunters varied widely (18-54) with many adherents in each age group, although the 35-44 age group had the greatest representation (22%). Other researchers, however, have noted marked increases in youth

Figure 8. The National Archery in the Schools Program (NASP) consists of team and individual competition from elementary through high school. The program includes a curriculum on bowfishing. Images courtesy of Oklahoma Department of Wildlife Conservation.

archery participation, such as a doubling of participation rates for young women over the period 2012-2016 (Heldman 2016; Fig. 8).

Media access – Increased media access has played an important role in creating a new generation of archers. Though bowfishing has yet to achieve pop culture prominence in the United States, some television programs and many YouTube channels are devoted to the sport. *Ironman Bowfishing* aired 11 episodes in 2013 but was not renewed and archived episodes are not readily available on any streaming service. *Bowfishing TV* was launched in 2018 and aired episodes in 2019 on various cable and satellite television providers. Heldman's (2016) general archery respondents across all ages and both sexes indicated that popular archers from movies such as Robin Hood (23%) and Katniss Everdeen (*The Hunger Games* franchise, 15%) influenced their decision to take up archery; the latter possibly influencing the growth in participation among young women.

Other media besides network television are increasingly important in the proliferation of the sport. Several equipment manufacturers produce videos on bowfishing for YouTube featuring their products. The top ten bowfishing videos on YouTube are not affiliated with specific manufacturers, however, and each one boasts between 5.8 and 46 million views. Diverse media outlets have undoubtedly increased the access to immediate and detailed bowfishing information of all types far beyond what was possible a few decades ago. Both long-term and new adherents to bowfishing have increasingly more immediate, up-to-date information on gears, techniques, and specific bowfishing locations, all designed to increase their enjoyment and their success. Sustainable management of bowfishing, like nearly all other fisheries, must occur in an environment of continually increasing efficiency by bowfishers (Sanders and Morgan 1976).

Sport Governance and Bowfishing Tournaments

Bowhunting has a long history of governance in the United States. The earliest record of organized archers was The United Bowman

of Philadelphia, an exclusive club founded in 1828 by Titian Ramsey Peale. As recounted by Elmer (1917), Peale, an assistant naturalist in the western expeditions of Major Stephen Long, learned archery from the native tribes and drew on experiences with English archery clubs in forming his club. The Bowmen disbanded in 1858, and "archery … remain[ed] in desuetude for twenty years" (p. 10, Elmer 1917). In 1879, the National Archery Association was established, with Maurice Thompson serving as its first president. Known today as USA Archery and headquartered in Colorado Springs, Colorado, it serves "to foster and promote the sport of archery [and to] provide the necessary resources to foster strong athlete participation, competition and training in the sport of archery" [www.usarchery.org]. The National Field Archery Association (NFAA), founded in 1939, is "a non-profit corporation dedicated to the sport of archery and is the largest field archery organization in the world" [www.nfaausa.com]. NFAA now consists of 49 chartered state associations and nearly 1,000 affiliated clubs. It promotes numerous competitions for archers of all ages and interests.

Beyond the umbrella supervision and coordination of such organizations for the sport of archery, specific governance of the expanding sport of bowfishing is, perhaps understandably, in a state of development. The sport of bowfishing in the United States is unofficially coordinated by the Bowfishing Association of America (BAA), which incorporated in 1989 to "manage bowfishing tournaments in the United States" as an official sanctioning body and record keeper [www.bowfishingassociation.com]. The Archery trade Association (ATA), although established in 1953, only recently developed and launched its "Explore Bowhunting" curriculum in 2011 to supplement the National Archery in the Schools Program. Even more recently, in 2016, ATA launched the "Explore Bowfishing" companion program "as a response to state agencies" requesting a curriculum for bowfishing, which was "growing in popularity across the country" (ATA 2019; Fig. 8).

Table 1. Summary of Great Lakes Bowfishing Championship tournament take data from http://glbc-caseville.com/history.htm

Year	Weight (kg)	Teams	Average Weight (kg)
1984	2,249	20	112
1985	6,187	38	163
1986	6,504	123	53
1987	32,713	175	187
1988	18,768	177	106
1989	54,967	189	291
1990	34,638	200	180
1991	25,650	225	114
1992	60,781	230	264
1993	73,481	230	319
1994	58,640	250	235
1995	28,001	250	112
1996	126,494	250	505
1997	7,132	250	29
1998	7,970	250	32
1999	38,475	250	154
2000	42,919	250	171
2001	12,392	250	49
2002	110,043	228	483
2003	23,707	250	95
2004	43,624	250	175
2005	35,561	250	143
2006	38,870	245	159
2007	27,564	234	121
2008	38,012	232	164
2009	38,034	210	181
2010	19,289	217	89
2011	66,171	208	318
2012	67,464	238	283
2013	25,655	250	103
2014	10,495	230	46
2015	46,718	239	195
2016	51,829	250	210
2017	5,024	250	20
2018	21,234	262	81
2019	15,349	266	58
Total	1,322,604		
Average	36,739	220	167

A few bowfishing tournaments boast decades-long histories. For example, the Great Lakes Bowfishing Championship (GLBC) has been held annually in Saginaw Bay, Michigan since 1984 (Table 1). The GLBC began humbly, with 20 tournament participants, but increased six-fold in three years and hosted a record-high 266 teams in

Table 2. Summary of high-profile bowfishing tournaments.

Tournament Name	Est.	Location	Format	Total prize $	URL	Waters
US Open Bowfishing Tournament	2013	Various	Big 20	$100,000	https://www.basspro.com/shop/en/usopen	Multiple
Cajun 8	2015	IN	Big 8	$29,000	https://cajunbowfishing.com/cajun-8/	Multiple
AMS Big 20 Challenge	2011	WI	Big 20	$24,000	https://www.amsbowfishing.com/big20/	Multiple
Carp Madness Bowfishing	2017	KY	Total weight	$23,000		Multiple
Muzzy Classic	1999	KY	Big 20	$22,500	https://www.theoutdoorwire.com/releases/5873d724-2bdd-4a27-a227-1d81820e73b8	Multiple

2019. This two-day tournament saw the winning team take 442 kg of fish in 2019 for a portion of the $9,000 in prizes. High-profile tournament popularity growth appears to be mostly a recent phenomenon, however, as the most prominent bowfishing tournaments (relative to their total prize money) were established within the last decade (Table 2). Popularity extends to lower-profile and regional tournaments, as the BAA sanctioned 64 tournaments in 2018, with most occurring in summer months (Fig. 9).

Species composition of bowfishing tournament take varies widely based on tournament format, timing, location, local regulations, and other factors. For example, in the 2016 U.S. Open in Memphis, Tennessee, take was restricted to nonnative carps (Bighead, Common, Grass, and Silver) as an awareness promotion for the Great American River Cleanup (Ammoland 2016). When no such taxonomic restrictions were in place, Suchan (2014) reported that Common Carp comprised 85% of the U.S. Open take in 2014 in southwest Missouri. In contrast, however, the 2018 U.S. Open tournament take in northeast Oklahoma was dominated by native buffalofishes (55%) and gars (25%) while nonnative carps comprised only 17% of the take (Table 3). Timing of tournaments to coincide with shallow water spawning activities for many of the preferred species (e.g. gars, carps, and suckers) typically results in many tournaments being scheduled

Table 3. Bowfishing take by species for 2018 U.S. Open Tournament participants. Group % indicates the summed species % within group. Culled fish are not included here.

Group	Species	Count	Species %	Group %
Native buffalofishes	Smallmouth Buffalo *Ictiobus bubalus*	1,404	50.8	54.5
	Bigmouth Buffalo *Ictiobus cyprinellus*	102	3.7	
Native gars	Longnose Gar *Lepisosteus osseus*	621	22.5	25.4
	Shortnose Gar *Lepisosteus oculatus*	49	1.8	
	Spotted Gar *Lepisosteus platostomus*	33	1.2	
Nonnative carps	Common Carp *Cyprinus carpio*	321	11.6	17.0
	Grass Carp *Ctenopharyngodon idella*	150	5.4	
Other native species	River Carpsucker *Carpiodes carpio*	53	1.9	3.1
	Freshwater Drum *Aplodinotus grunniens*	26	0.9	
	Quillback *Carpiodes cyprinus*	3	0.1	
	Blue Sucker *Cycleptus elongatus*	2	0.1	
	Spotted Sucker *Minytrema melanops*	1	0.0	
	Total	2,765		

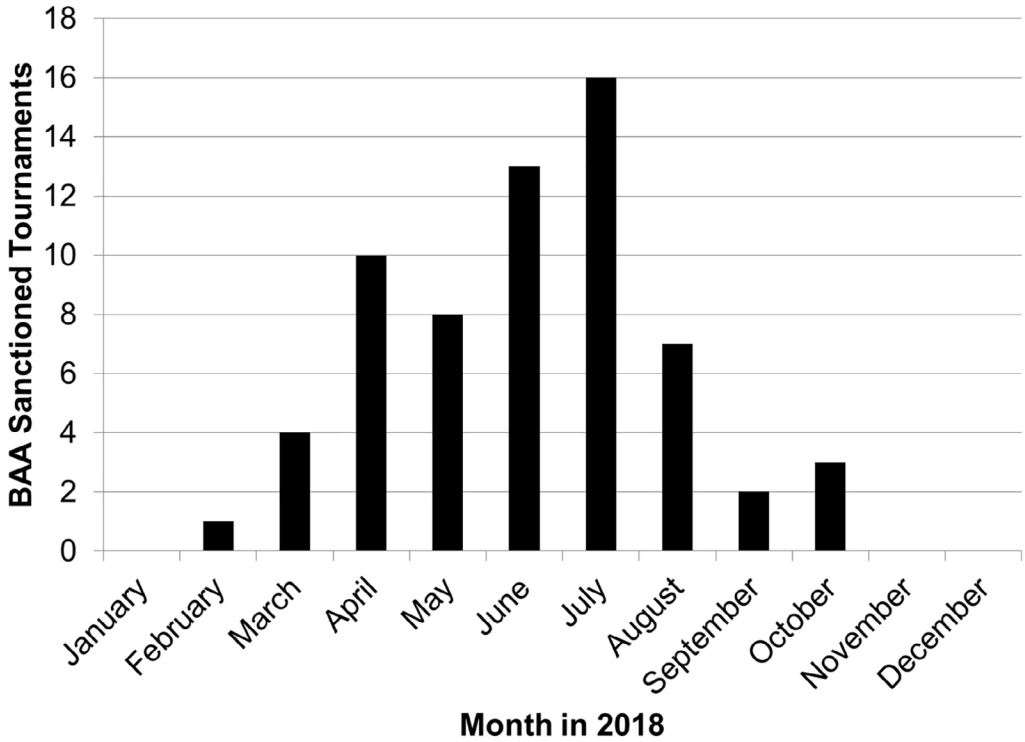


Figure 9. Monthly summary of bowfishing tournaments (n=64) sanctioned by the Bowfishing Association of America (BAA) in 2018.

during the period April-June, with regional variances due to water temperature and climate.

Case study: Bass Pro® U.S. Open Bowfishing Championship

Often regarded by insiders as the "Super Bowl of Bowfishing," the U.S. Open Bowfishing Championship is a high-profile event in recreational bowfishing. Begun in 2013 in southwest Missouri, the tournament has achieved prominence through large corporate sponsorships, large purses, and a regional drawing for competitors (Table 4). On June 2-3, 2018, Bass Pro Shops® Broken Arrow, Oklahoma, hosted the 6th annual U.S. Open Bowfishing Championship (U.S. Open; Fig. 10). The tournament was open statewide on legal bowfishing waters and species, however, Paddlefish and Alligator Gar *Atractosteus spatula* were not allowed at the weigh-in (each has a daily bag limit of one and both are subject to special regulations in Oklahoma). The tournament began at 6pm on June 2 and was open to 250 watercraft with teams of 2 to 4 bowfishers. Weigh-in occurred at 8am on June 3, allowing a maximum of 14h for travel and bowfishing. Because the tournament was scheduled on the Oklahoma Department of Wildlife Conservation (ODWC) statewide "Free Fishing Weekend," team members were not required to possess state fishing licenses.

Sampling the fish and fishery - ODWC partnered with tournament sponsors to collect information on take, pressure, demographics, motivations, and other important characteristics from bowfishers to inform future state management. ODWC's involvement was three-fold: providing an information and education booth, participating in the fish counts and weights, and facilitating a bowfisher survey.

Table 4. Summary of Bass Pro Shops® U.S. Open Bowfishing Championship weighed fish take (https://www.basspro.com/shop/en/us-open-results). Number of weighing teams is noted in parentheses when appropriate. Tournament take in 2016 solely comprised nonnative carps as part of the "Great River Cleanup." Data from the 2018 tournament were corroborated by independent surveys by the Oklahoma Department of Wildlife Conservation. Take totals do not include culled fish.

Year	Location	Tournament Teams	Weighed Fish	Weighed Take (kg)	Winning aggregate weight (kg)
2013	Ridgedale, Missouri	112	1,769	7,664	162
2014	Ridgedale, Missouri	175		12,274	171
2015	Springfield, Missouri	190		10,959	179
2016	Memphis, Tennessee	169 (107)		11,126	454
2017	Springfield, Missouri	100		4,948	161
2018	Broken Arrow, Oklahoma	170 (148)	2,765	11,061	192
2019	Bossier City, Louisiana	118 (94)		9,171	272
Total:				67,203	

ODWC staffed a table for the entire tournament weekend, interacting with tournament teams, families, and the general public with a goal of educating on fish identification, state fishing regulations, and other information on Oklahoma waters. Regulation booklets, Oklahoma Water Atlases, and carp recipe booklets were provided at no cost. ODWC also

Figure 10. Large crowds of participants and spectators gathered at the 2018 Bass Pro Shops® U.S. Open Bowfishing Championship in Broken Arrow, Oklahoma. Modified and purpose-built watercraft were utilized by 170 teams of 2-4 bowfishers in pursuit of nongame fishes with few harvest restrictions. Images courtesy of Kelly Bostian, Tulsa World © 2018.

Figure 11. Examples from interactive fish ID quiz administered to tournament participants and spectators at the 2018 Bass Pro Shops® U.S. Open Bowfishing Championship in Broken Arrow, Oklahoma.

performed a multimedia educational exercise via a fish identification quiz. Individuals were presented a photo of a fish and asked to classify it correctly with ten photos in each of the following pairings: Carp or Buffalo, Native or Invasive, Shortnose Gar *Lepisosteus platostomus* or Alligator Gar. Although scores were not recorded, the quiz was used to initiate conversations on fish identification valuable for bowfishers (Fig. 11).

At the June 3 weigh-in, teams selected their 20 largest fish and placed them in an official weighing bin while ODWC identified and enumerated the fish by species. All fish in excess of 20 were culled before leaving the water or on site and were not examined or weighed. Two 23m³ dumpsters were provided for disposal of all weighed-in and culled fish. Weigh-in consisted of an aggregate weight of the 20 largest fish for each team (aka "Big 20" tournament format). Individual weights and lengths were recorded for contenders for the "Biggest Fish" and "Longest Gar" prizes, respectively (Fig. 12).

While teams waited in the queue for the weigh-in, creel clerks surveyed tournament team captains with an oral survey recording answers digitally on a cellular phone via Google® Forms. Clerks recorded team number, home zip code, number of male and female bowfishers, total hours fished, and waters fished. Team captains were also asked to state or approximate how many fish, in excess of their 20 weighed-in fish, were culled either on the water or at the weigh in. Lastly, team captains were asked to state their preferred species for bowfishing, which were later aggregated into coarse taxonomic groups (gars, carps, buffalofishes, and other).

Total take was estimated by summing the weighed fish with the approximate number of culled fish reported in the bowfisher survey. Culled fish were not identified by species, so species weights could not be estimated. Bowfishing take per hour was estimated by multiplying the reported hours of fishing by all team members for each team to estimate total hours fished. The number of fish killed (weighed

Figure 12. Team "Line 'Em Up" poses with 3 of 20 large Longnose Gar which comprised their winning take of 192 kg and earned them a victory at the 2018 Bass Pro Shops® U.S. Open Bowfishing Championship in Broken Arrow, Oklahoma. Image courtesy of Kelly Bostian, Tulsa World © 2018.

plus culled) for each team was then divided into the total hours fished. Total take by species was summed from the weighed fish; however, aggregate weights by species were not recorded. The frequency of taxa within the weighted take for each team was compared to stated preferences for target species from the survey via a Chi-Square test (significance level of $\alpha = 0.05$).

Demographic analyses included approaches for estimating distance traveled: distance from home to the tournament based on home zip code to the weigh-in site in Broken Arrow, Oklahoma. Second, actual driving distance was estimated between all fished bodies of water via Google® Maps, assuming the shortest possible route between ramps. Total distance traveled during the tournament, including transit to and from home, was estimated for each team. All data compiled on fish counts, fish weights, and from bowfisher surveys were linked by team number in a relational database.

Each water body reported as fished was classified as "clean" or "contaminated" based on the ODWC list of restricted waters due to the presence of Aquatic Nuisance Species (ANS; e.g. Zebra Mussels *Dreissena polymorpha*, Didymo *Didymosphenia geminata*, and others). Potential risk of contamination of clean waters from ANS contaminated waters was assessed based on survey responses from teams bowfishing multiple water bodies. Using the shortest driving distance method described above and assuming that all tournament boats were initially clean, teams that potentially moved from contaminated waters to clean waters were identified and the overall fraction of water body visits by contaminated watercraft among all reported visits served as an indicator of contamination risk due to the tournament.

Characterizing the tournament and its participants - Of the 170 teams registered, fish counts were obtained from 148 teams, and bowfisher surveys from 147 teams. The remainder of teams opted out of the weigh-in events or were not available to survey. The total number of fish weighed-in was 2,765, representing 12 species (Table 4). Total weight of weighed-in fish was 11,061 kg with the winning and average team weights of 192 kg and 74 kg, respectively. Most of the killed fish weighed-in (55%) consisted of native buffalofishes (51% Smallmouth *Ictiobus bubalus* and 4% Bigmouth *I. cyprinellus*), 25% native gars (22% Longnose *L. osseus*, 2% Shortnose, and 1% Spotted *L. oculatus*), 17% nonnative carps (12% Common Carp and 5% Grass Carp), and the remaining 3.1% comprising other native, nongame species (Table 3). Native, nongame species constituted 83% of the killed fish weighed-in. Two Blue Sucker *Cycleptus elongatus* (an Oklahoma species of Special Concern Category II with

a daily bag limit of one and mandatory take reporting) were observed in the weighed-in take, but the total take of this species is not known.

Seventy-four percent of teams killed 20 or more fish (including culled fish). In addition to the reported take at weigh-in, teams reported culling an estimated 1,919 fish (average 13 fish per team, maximum 90), which did not contribute to the species composition profile or weights. Species composition of culled fish was not reported. Including the culled fish, the estimated total take for the tournament was 4,684 fish.

Team captains completed a survey on behalf of 516 bowfishers (500 males, 16 females) originating from 13 states. Teams traveled an average of 370 km one-way to participate in the tournament, with four teams traveling more than 1,638 km. Participants bowfished a combined 4,953 hours.

Statewide, 29 water bodies were bowfished, with 52% of teams fishing multiple water bodies (2-4) and four teams reported logging >322 km in total estimated distance traveled from the weigh-in site. Thirteen water bodies fished (45%) were known ANS waters in Oklahoma (C. Tackett, ODWC, personal communication). Further, 13 teams (9%) bowfished combinations of two or more bodies of water comprising ANS waters and non-ANS waters, where contamination potentially occurred (depending on the order in which they bowfished these waters).

Half of teams reported a preference for shooting gars (50%), while 36% and 12% reported a preference for carps and buffalofishes, respectively. A significant difference was found between the species bowfishers wanted to shoot and what they shot (Chi-Square = 4,913, df = 3, $p<0.001$, Fig. 13). This discrepancy may be attributed to differences in species composition between tournament waters and home waters, a change in bowfishing strategy to increase tournament performance, or challenges with species identification, among other possible explanations. This inconsistency illustrates a difference between data gathered from an angler survey (either by mail or online) and data collected from actual take observed at a bowfishing tournament through a targeted survey.

National Status and State Regulation of Bowfishing

To better understand the (2019) status of bowfishing management in the United States, we administered a survey to all 50 state fish and wildlife agencies in April-July 2019. Emails with a link to the online survey were sent to a list of Fisheries Chiefs provided by the American Fisheries Society. Responses were provided by a mixture of Fisheries Chiefs and agency personnel designated by them as best qualified to respond. Responses were received from all states except Maine and New Jersey. In these two cases, we attempted to acquire the answers to survey questions through examination of online resources curated by their agency (e.g. fishing regulations or agency website). In five states, (Indiana, Louisiana, Maryland, Minnesota, and Oregon), separate responses were received from more than one qualified person. These responses were examined for similarity and thoroughness, and we selected the one we deemed to be the most thorough, informed response. States were grouped into U.S. Census Bureau regions: Midwest, Northeast, South, and West (Table 5).

Status - Responses indicated that bowfishing was legal in all 50 states, requiring only a general fishing license in 44 states (Table 5). Only one state (Iowa) reported requiring a specific bowfishing permit or license to participate in the sport. South Dakota previously required a spearing/bowfishing permit with a $5 fee to identify constituents eligible for a survey, but this permit and fee were discontinued in 2019.

Twenty-eight states reported having restrictions on where anglers were allowed to bowfish, and 17 states reported time of day or seasonal

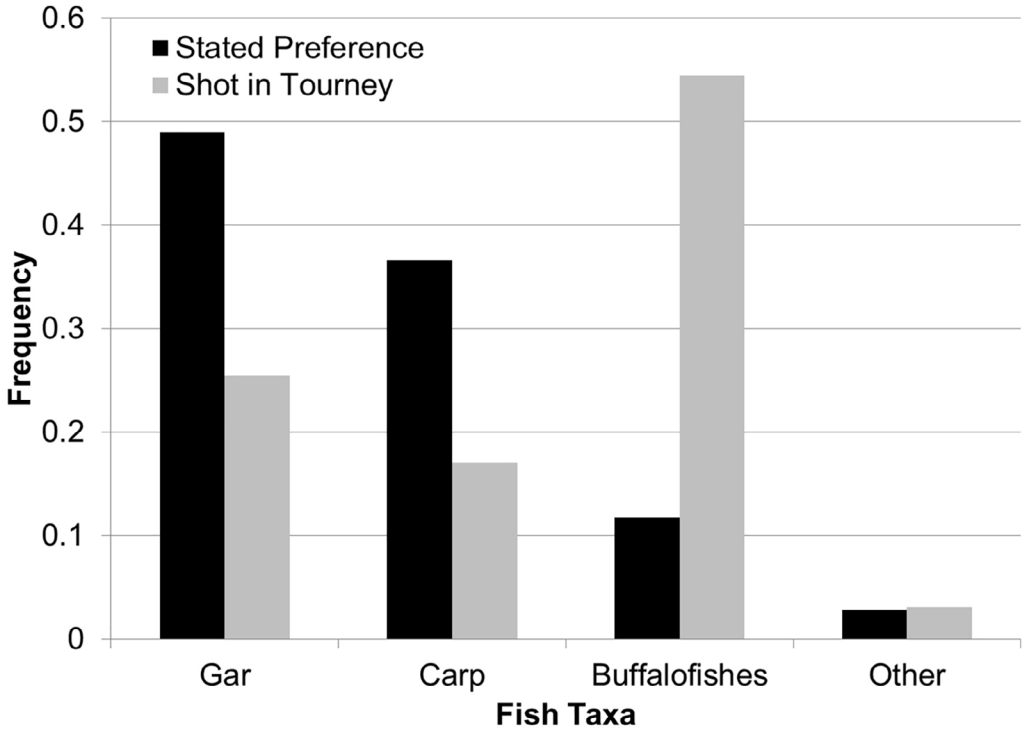


Figure 13. Stated preference for taxonomic guild as reported by Bass Pro Shops® U.S. Open Bowfishing Tournament 2018 teams compared to actual composition of their take. Difference between stated preference and take was significant (Chi-square = 4,913, df = 3, p<0.001).

restrictions. Only 12 states utilized both types of these restrictions. For example, certain Minnesota waters managed for trout or posted as "spawning areas" were closed to bowfishing. Further, certain area restrictions applied during an "early season" (typically scheduled from late February to late April) which did not apply elsewhere or during the remainder of the year (Minnesota Department of Natural Resources 2020). South Dakota provided a fall bowfishing opportunity in Lake Oahe for Chinook Salmon *Oncorhynchus tshawytscha*, but other nongame species were vulnerable to bowfishing in all state waters year-round. When states were grouped by region, a higher proportion of Midwest states (42%) used time and area restrictions to regulate bowfishing participation, whereas fewer states in other regions utilized both (Northeast- 30%, West- 15%, and South- 13%).

Half of the state respondents (25) reported the opinion that bowfishing was increasing in popularity in their respective states, while 16 states reported bowfishing as having stable popularity. However, no technical justification for this opinion was required of the respondents. Most states (30) reported having bowfishing tournaments in their states, with half of these states unable to specify the number of tournaments. Many states reported efforts or a desire to promote the sport by means of creating opportunities through relaxing regulations on certain valued species (e.g. catfishes (Ictaluridae): Texas and Wisconsin; salmon (Salmonidae): Montana and South Dakota; Northern Pike Esocidae*: Esox lucius* : North Dakota), opening new areas for bowfishing (Oregon and Montana), removing permitting barriers or fees (South Dakota), promoting the sport in general (Maryland and

Table 5. Results of an online bowfishing management survey administered to 50 state fish and wildlife agencies. States noted with an asterisk (*) did not respond to the survey and answers were derived solely from online resources. Omitted or missing responses are noted with a dash (-). U.S. Census Bureau regions are indicated (Northeast [NE], Midwest [MW], South [S], and West [W]).

		Status and Regulation						Tournaments		Challenges	
		Q5	Q6	Q7	Q8	Q9	Q10	Q11,12	Q13	Q15	Q16
State	Region	Legal?	License Type?	Area Restrictions?	Time Restrictions?	Monitoring?	Popularity?	Tournaments? (#?)	Mgmt. Concerns ?	Education Programs ?	Goals / Plan?
AK	W	Y	Fishing	Y	N	None	Stable	N (0)	-	N	N
AL	S	Y	Fishing	N	N	None	Stable	Y (Unk)	N	N	N
AR	S	Y	Fishing with Taxa Permit	N	Y	Statewide Survey	Increasing	Y (Unk)	N	N	N
AZ	W	Y	Fishing	Y	N	None	Stable	Y (1-10)	N	N	N
CA	W	Y	Fishing	Y	N	None	Increasing	Unk. (-)	-	N	N
CO	W	Y	Fishing	N	N	Statewide Survey	Stable	Unk. (-)	-	N	N
CT	NE	Y	Fishing	Y	N	None	Stable	N (0)	Y	N	N
DE	NE	Y	Fishing	N	N	None	Increasing	Unk. (-)	-	N	N
FL	S	Y	Fishing	N	N	None	Unknown	Y (Unk)	N	Youth only	N
GA	S	Y	Fishing	Y	Y	None	Increasing	Unk. (-)	-	N	N
HI	W	Y	-	N	N	None	Unknown	N (0)	-	N	N
IA	MW	Y	Fishing with Bow Permit	N	N	None	Increasing	Y (11-20)	N	Youth and Adult	N
ID	W	Y	Fishing	N	Y	Statewide Survey	Increasing	Y (1-10)	N	N	N
IL	MW	Y	Fishing	Y	Y	Bowfishing Survey	Stable	Y (31-40)	Y	Youth and Adult	N
IN	MW	Y	Fishing	N	N	Statewide Survey	Increasing	Y (Unk)	Unknown	Youth and Adult	N
KS	MW	Y	Fishing	Y	N	None	Unknown	Y (Unk)	Unknown	N	N
KY	S	Y	Fishing	Y	N	None	Increasing	Y (Unk)	N	N	N
LA	S	Y	Fishing	N	N	None	Increasing	Y (Unk)	N	N	N
MA	NE	Y	Fishing	N	N	None	Stable	N (0)	-	N	N
MD	S	Y	Fishing	Y	N	None	Increasing	Y (Unk)	Y	N	N
ME*	NE	Y	Fishing	Y	Y	-	-	-	-	-	-
MI	MW	Y	Fishing	Y	N	None	Increasing	Y (11-20)	N	N	N
MN	MW	Y	Fishing	Y	Y	Statewide Survey	Increasing	Y (Unk)	Y	N	N
MO	MW	Y	Fishing	N	Y	None	Increasing	Unk. (-)	-	N	N
MS	S	Y	Fishing and/or Hunting	N	N	None	Unknown	Unk. (-)	-	N	N
MT	W	Y	Fishing	Y	N	Bowfishing Survey	Increasing	Y (1-10)	N	N	N
NC	S	Y	Fishing and/or Hunting	Y	N	None	Increasing	Y (Unk)	Y	N	N
ND	MW	Y	Fishing	N	N	None	Stable	Y (1-10)	N	N	N
NE	MW	Y	Fishing	Y	Y	None	Increasing	Y (1-10)	N	N	N
NH	NE	Y	Fishing	Y	N	None	Unknown	N (0)	N	N	N
NJ*	NE	Y	Fishing	Y	N	-	-	-	-	-	-
NM	W	Y	Fishing	Y	N	Statewide Survey	Stable	Unk. (-)	-	N	N
NV	W	Y	Fishing	Y	Y	None	Stable	N (0)	-	Youth and Adult	N
NY	NE	Y	Fishing and/or Hunting	N	Y	None	Increasing	Unk. (-)	-	N	N
OH	MW	Y	Fishing	N	N	None	Stable	Y (Unk)	N	N	N
OK	S	Y	Fishing	Y	N	None	Increasing	Y (>50)	Y	Youth only	N
OR	W	Y	Fishing	N	N	None	Increasing	Y (1-10)	N	Youth and Adult	N
PA	NE	Y	Fishing	Y	Y	None	Increasing	Y (21-30)	Y	N	N
RI	NE	Y	Fishing	N	N	None	Unknown	N (0)	-	N	N
SC	S	Y	Fishing	Y	N	None	Increasing	Y (Unk)	Unknown	N	N
SD	MW	Y	Fishing	Y	Y	Bowfishing Survey	Increasing	Y (1-10)	N	Youth and Adult	N
TN	S	Y	Fishing	Y	N	Statewide Survey	Increasing	Y (Unk)	Unknown	N	N
TX	S	Y	Fishing	Y	Y	Statewide Survey	Increasing	Y (Unk)	Unknown	Youth and Adult	Unknown
UT	W	Y	Fishing	Y	Y	Statewide Survey	Stable	Unk. (-)	-	N	N
VA	S	Y	Fishing	N	N	Statewide Survey	Stable	Y (41-50)	Y	N	N
VT	NE	Y	Fishing	Y	Y	None	Stable	Y (1-10)	Unknown	N	N
WA	W	Y	None	N	N	None	Increasing	Y (Unk)	N	N	N
WI	MW	Y	Fishing	Y	Y	Statewide Survey	Stable	Y (1-10)	Unknown	N	N
WV	S	Y	Fishing	N	Y	None	Unknown	N (0)	-	N	N
WY	W	Y	Fishing	N	N	None	Stable	N (0)	-	N	N
Totals		Yes=50 No=0	Fishing=43 Fish/Hunt=3 Bow=1 Taxa=1 None=1	Yes=28 No=22	Yes=17 No=33	None=34 SWS=11 Bow=3	Incr.=25 Stable=16 Unk.=7	Yes=30 No=9 Unk.=9	Yes=8 No=17 Unk.=7	Youth=2 Yth/Adult=7 None=39	Yes=0 No=47 Unk.=1

Table 6. States with known numbers of bowfishing tournaments held annually reporting on management concerns with these tournaments.

No. of Bowfishing Tournaments	Management Concerns? Yes	No	Unknown
1-10		AZ, ID, MT, ND, NE, OR, SD	VT, WI
11-20		IA, MI	
21-30	PA		
31-40	IL		
41-50	VA		
>50	OK		
Totals	4	9	2

Nevada), or utilizing the sport as a means of invasive species control (e.g. invasive carps: Mississippi, Michigan, Tennessee, and Washington; Northern Snakehead *Channa argus*: Delaware, Maryland, and Mississippi). For states reporting increasing popularity, 80% reported having tournaments with the remainder reporting unknown status of tournaments (no states with increasing popularity reported having no tournaments). States reporting stable popularity were more balanced between those having tournaments (50%), not having tournaments (31%), and unknown tournament status (19%). Because the dimensions of a bowfishing tournament were not solicited in the survey, the criteria might be unique for each state. As described above in the governance section, the Bowfishing Association of America reported sanctioning of only 64 tournaments in 2018 (Fig. 9); however the number of unsanctioned tournaments nationwide was likely far greater, especially when considering four states reported more than 20 tournaments per year (Table 6). Respondents from states with knowledge of the quantity of bowfishing tournaments primarily reported few (1-10) tournaments annually (nine states), while two states (Oklahoma and Virginia) reported >50 and 41-50 tournaments, respectively. Few states with tournaments (4 of 15) reported having management concerns about bowfishing tournaments; however, a clear relationship between quantity of tournaments and management concerns was evident in the data (Table 6). Only states reporting 21 or more tournaments noted management concerns with bowfishing tournaments.

Management concerns - All but one state (Mississippi) reported one or more bowfishing management concerns. States reporting increasing popularity of bowfishing reported a higher number of management concerns (average 4.6) than states reporting stable popularity (average 3.3). However, this difference was not statistically significant (Unpaired T-Test; $p=0.059$; Fig. 14). The most common concerns (i.e., greatest number of states) were inadequate data on bowfishers (71%) and bowfishing take (63%, Table 7). Additional concerns, ranked by frequency, included wanton waste, user conflicts, public perception or ethics, and inadequate data on bowfished species. Other concerns were noted by fewer than 21% of states. States that reported having bowfishing tournaments also reported significantly more individual management concerns (average 4.7) than states reporting no tournaments (average 1.9, Unpaired T-Test $t = 3.89$, $df = 40$, $p<0.001$). The prevalence of state concerns related to data inadequacies appears to square with the self-reported inadequacies in monitoring, frequency of "Unknowns" reported in the survey, and the universal lack of bowfishing management goals or plans.

Wanton waste was identified as a common concern. The term was presumed to be understood by survey respondents as having two aspects: one regarding the lack of use of killed fish and the other as inappropriate or illegal (in some states) disposal of killed fish or carcasses as the result of bowfishing (Fig. 15). The respondent from Tennessee reported that carcass discards were a concern, but that there is no wanton waste law in their state. This response was pooled with other concerns of wanton waste, however, despite this legal caveat. The additional concern of public

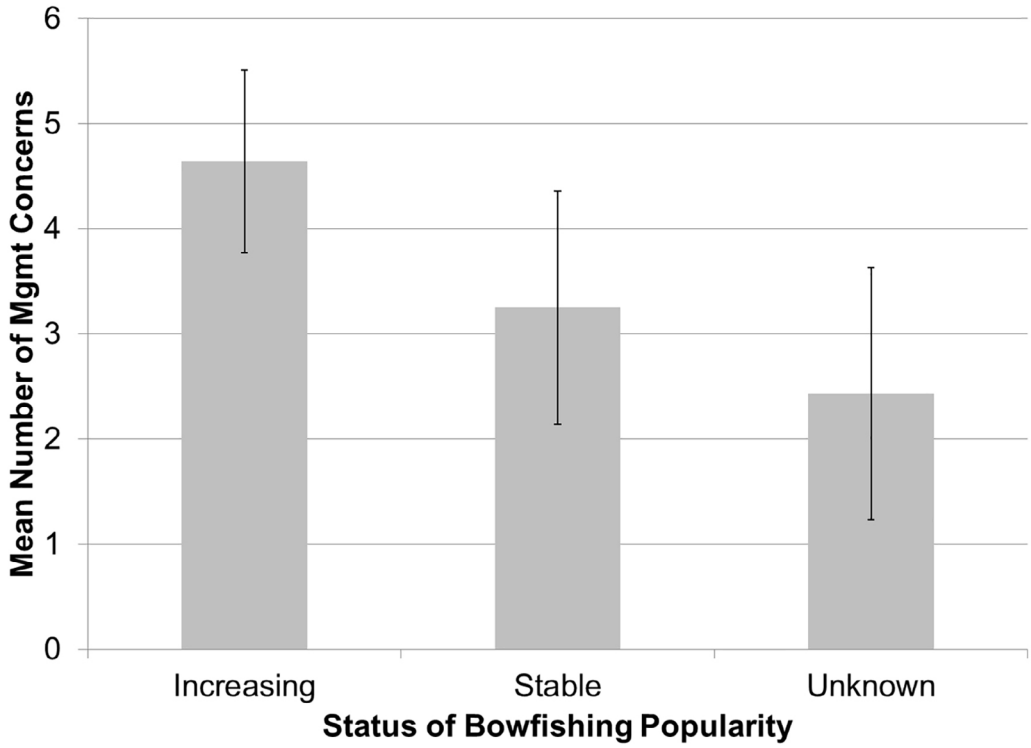


Figure 14. Comparison of number of management concerns noted by states reporting increasing, stable, or unknown popularity of bowfishing. Error bars represent 95% confidence intervals.

perception or ethics may be related, as 12 of the 21 states concerned with public perception or ethics also noted a concern with wanton waste.

User conflicts were a noted concern by 22 states, and the specific nature of this concern was identified by only a few states. Three (Connecticut, Pennsylvania, and Oregon) highlighted the tendency of bowfishers to kill trophy Common Carp, which was at odds with the priorities of hook and line carp anglers, who have stated a preference for catch and release. An additional two states (Idaho and New York) recognized the potential for this conflict in the future, as carp angling was reported to be increasing in popularity. Pennsylvania noted a user conflict between bowfishers and fishing guides leading anglers to trophy Flathead Catfish *Pylodictis olivaris* and Channel Catfish *Ictalurus punctatus*. This concern contrasted with that of Wisconsin, which recently allowed the bowfishing of catfish and reported no notable concerns or user conflicts. Indiana and Pennsylvania noted an increasing frequency of illegal take (or shoot and release) of game fishes, which would constitute a user conflict with anglers pursuing legal means of take. Minnesota reported user conflicts with lake shore property owners related to noise of generators used to power lights on bowfishing watercraft.

Fisheries Monitoring - Only three states (Illinois, Montana, and South Dakota) reported a bowfishing monitoring program, but 11 states included bowfishing in a larger statewide angler survey while most states (71%) did not monitor bowfishing or bowfishers (Table 5). One exception was Michigan, which had recently completed a statewide analysis of bowfishing activity (Diana and Goniea 2019).

Table 7. Summary of management concerns voiced by state fish and wildlife agencies in an online bowfishing management survey. Maine and New Jersey did not respond to the survey and Mississippi noted no concerns.

	Management Concerns											
State	Inadequate Data on Bowfishers	Inadequate Data on Take	Inadequate Data on Species	Fish Identification	User Conflicts	Wanton Waste	Poaching	Aquatic Nuisance Species	Public Safety	Inadequate Bowfishing Education	Public Perception / Ethics	Other
AK								1				
AL	1	1	1		1	1						
AR	1	1	1			1						
AZ	1	1	1		1					1	1	
CA	1	1	1									
CO	1	1										
CT	1	1			1	1					1	
DE	1	1			1		1			1	1	
FL	1	1					1					
GA				1	1	1						
HI	1	1	1									
IA	1	1	1			1	1	1	1			
ID					1							
IL	1	1	1	1		1		1			1	
IN	1	1	1	1	1	1				1		
KS	1			1	1	1	1					
KY		1										
LA	1	1			1						1	
MA												1
MD	1					1						
MI	1	1	1		1	1					1	
MN	1	1			1	1					1	
MO	1	1	1		1	1	1				1	
MT		1			1		1				1	
NC	1	1	1	1	1	1	1				1	
ND						1						
NE	1	1	1			1						
NH	1											1
NM	1	1			1						1	
NV	1											
NY											1	
OH	1	1	1								1	
OK	1	1	1	1	1	1	1	1		1	1	
OR	1							1		1	1	
PA					1	1	1		1			
RI	1	1	1									
SC	1	1		1	1	1					1	
SD					1	1		1	1		1	
TN	1	1	1		1	1						
TX	1		1		1	1					1	
UT											1	
VA	1	1	1			1	1					
VT	1	1		1	1	1					1	
WA	1	1				1						1
WI	1	1									1	
WV						1						
WY												
Totals	34	30	18	8	22	25	10	6	3	5	21	3

Figure 15. Example of wanton waste after a night of bowfishing on a Tennessee River reservoir, Alabama. These carcasses of native buffalofishes and other Cypriniform species (both native and nonnative) were discarded next to a boat ramp. Image courtesy of Chris Kim.

Bowfishing Education - Only nine states reported having bowfishing education programs (Florida, Iowa, Illinois, Indiana, Nevada, Oklahoma, Oregon, South Dakota, and Texas). Only five states noted inadequate bowfishing education as a management concern. However, three of these (Indiana, Oklahoma, and Oregon) reported having bowfishing education programs for youth and/or adults. Fish identification, a likely component of bowfishing education programs, was only noted as a concern by eight states. Three of these (Illinois, Indiana, and Oklahoma) reported having bowfishing education programs, possibly indicating inadequacies in the curriculum, implementation, or reach of these programs.

Management Planning - No states reported having articulated bowfishing management goals or plans.

Regional patterns - When grouped by U.S. Census regions, bowfishing management survey responses revealed several regional patterns (Table 8). Midwest and South states were similar in respect to high fractions of states reporting increasing popularity of bowfishing and the presence of tournaments. In contrast, Northeast and West states reported lower popularity and fewer tournaments. Midwest states reported the greatest average number of management concerns per state (5.1). Northeast and West states, where a minority reported increasing popularity of the sport, had fewer management concerns compared to other regions. Midwest and South states generally agreed that data inadequacies (on bowfishers, take in general, and species killed) were management concerns. While wanton waste was an important management concern noted by a

Table 8. State management agency survey responses (proportions) grouped by U.S. Census regions. The Northeast region includes ten states; however, responses were not received from two states (Maine and New Hampshire), therefore all calculations are performed using the responses from eight states.

					Individual Management Concerns										
Region (# of states)	Popularity Increasing	Has Tournaments	Has Education Programs	Avg. # Mgmt. Concerns per State	Inadequate Data on Bowfishers	Inadequate Data on Take	Inadequate Data on Species	Fish Identification	User Conflicts	Wanton Waste	Poaching	Aquatic Nuisance Species	Public Safety	Inadequate Bowfishing Education	Public Perception / Ethics
Midwest (12)	0.58	0.92	0.33	5.1	0.83	0.75	0.58	0.25	0.50	0.83	0.25	0.25	0.17	0.08	0.58
Northeast (8)	0.38	0.25	0.00	3.5	0.63	0.50	0.13	0.13	0.50	0.38	0.25	0.00	0.13	0.13	0.50
South (15)	0.60	0.80	0.20	4.1	0.73	0.67	0.47	0.27	0.53	0.73	0.27	0.07	0.00	0.07	0.33
West (13)	0.38	0.38	0.15	2.6	0.62	0.54	0.23	0.00	0.31	0.08	0.08	0.15	0.00	0.15	0.38

high fraction of both Midwest (83%) and South (73%) states, public perception was reported at a lower frequency among South states (38%) compared to Midwest (58%). Fish identification was not reported as an important management concern by Western states (0%) though ANS was reported by several states (15%). Perhaps the buffalofishes (commonly mistaken for nonnative carps), whose native ranges are restricted to watersheds east of the Rocky Mountains, leaves few native, western species of similar appearance to nonnative carps. Although many of the management concerns noted could be assuaged, in part, through robust bowfishing education programs, few states in each region (8-15%) noted inadequate bowfishing education programs. Ironically, the two regions noting the fewest management concerns (Northeast and West) also reported the greatest (though low at 13 and 15%, respectively) concern for inadequate bowfishing education.

Other responses - While a standard fishing license is generally adequate to participate in bowfishing in most states (Table 5), we did not inquire about specific regulatory questions such as bag limits, size limits, taxon-specific bowfishing rules, or catch and release limitations for the sport. Relevant information was nevertheless provided by some respondents. For example, in Oklahoma, bowfishing is legal for all nongame fishes, including Alligator Gar and Paddlefish. Both species are pursued via snagging and bowfishing, have a daily limit of one, no size limit, and mandatory take reporting. However, mandatory retention is required for bowfished Alligator Gar and Paddlefish (no release); further, bowfishing is prohibited for Paddlefish when and where catch and release is required (ODWC 2019). For all other nongame fishes, catch and release is not prohibited for snagging and bowfishing. Studies on release mortality are not available. Bowfishing for Paddlefish in Montana is regulated through a tag system (one fish per person) below Fort Peck Lake (Montana Fish, Wildlife and Parks 2019). The Montana respondent noted a current consideration for regulations to allow bowfishing for Chinook Salmon, a non-native species in that state, in Fort Peck Lake.

The need for management of bowfishing

> *"In the harvest management of fishery resources in the inland United States, … decisions are often enacted by state agencies, acting under the Public Trust Doctrine. Under this Doctrine…, the fish resources are held in trust by the government for the benefit of the entire public; state agency fishery biologists act as trust managers …in administering actions to meet this commitment to sustainability for the benefit of present and future generations."* Rider et al. 2019, p. 269.

> *"There are no limits on rough fish, so you can shoot as many as you want and when you shoot one fish you just kind of want to keep getting more and more…"* – Matt Schillinger, AMS Bowfishing event coordinator (Skurzewski 2017).

> *"Bowfishing combines the skill of archery with the thrill of fishing. Bowfishing is also great for the environment. By harvesting hundreds of thousands of "garbage fish" a year, bowfishermen help bring equilibrium back to the ecosystem."*- Shootingtime.com (2020)

> *"Let your bending in the Archer's hand be for gladness, for even as He loves the arrow that flies, so He loves also the bow that is stable.*"(p. 18) – Kahlil Gibran, The Prophet; 1923; "On Children"

For the Kahlil Gibran (1923) quote above, one interpretation is that while the new generation of *Homo sapiens* is free like arrows to fly and self-actualize, the older generation, without owning the new, can provide overarching direction, wisdom and guidance to assist them. The steady hands of an individual pulling back a bowstring can be a prelude to enjoyable recreation, accomplishment, stress relief, and a return to a simpler time for the archer (Johnes 2004). So far from, and yet so close to, its artisanal origins, modern sport bowfishing's rapid expansion and technological advances in gear and media present new challenges for fisheries management agencies. The agencies must proactively act as stable bows in managing our common property fish stocks and fisheries for sustainability into future generations in this changing landscape of individualism: self-motivation, self-therapy, self-interest, and self-delusion (Odum 1982).

Pope (1918) described archery in the early 20th century as "nearly a lost art" (p. 103), largely forgotten by an emerging modern technological society. Like Lazarus of Bethany and Sam Resurrection (Fig. 2), however, the mystical art of archery has resurfaced to become a major sport, and as shown here, has again plunged its arrows into our waters in the modern sport of bowfishing. Even a half-hour perusal of internet websites depicts the fervor and enthusiasm that bowfishing has generated within the sporting public. In addition to private reports on media outlets, well-designed websites offer guided bowfishing trips from well-equipped outfitters, showing satisfied bowfishers posing next to their large, vanquished quarry. The bowfishing industry, true to entrepreneurial form, has developed and matured rapidly, both socially and technologically, in the past two decades. Increases in interest in bowfishing come in an era when other societal constituencies may seek, or be compelled to accept, less consumptive interactions with fish (e.g., Duffus and Dearden 1990; catch-and-release of Paddlefish: Cha and Melstrom 2018) associated with increasing human population and limited fishery resources. As of 2020, bowfishers are typically treated identically to anglers (i.e., hook and line) with respect to licensing. Yet creel surveys often fail to capture the needs and impacts of the bowfishing constituency as bowfishing is primarily and increasingly a nocturnal pursuit (e.g., Alligator Gar bowfishing, Bennett and Bonds 2012). Additional focus on bowfishers is afforded by the growth in popularity of bowfishing tournaments, where many bowfishers can be simultaneously observed in the same area. Bowfishers, like other fishers, are often regarded as secretive in respect to their fishing locations and habits, making this constituency particularly difficult to understand or monitor without targeted surveys, potential buy-in from tournament promoters, or cooperation from sanctioning bodies.

There is reason to ask whether the intended and potential impacts of bowfishing on fish stocks have been adequately articulated, considered, or documented by management agencies. Our 2019 survey of state fish and wildlife agencies, those primarily responsible for bowfishing management in most localities, indicated that

Figure 16. Asian carps, invasive planktivores, are strong candidates for providing abundant bowfishing opportunities with high or no bag limits. These nonnative species and other introduced carps are best able to meet the demand for live targets of bowfishers. The tendency to jump by Bighead Carp and Silver Carp adds another skill-testing dimension to bowfishing. Image courtesy of University of Illinois, Urbana.

no states had articulated specific management plans, including philosophical views on the sport, or goals and objectives for its orderly and sustainable development. Fewer than one in five states had specific education programs for a sport well-recognized as strongly compelling and potentially addictive to its enthusiastic participants (Clark 2014; also see Griffiths and Auer 2019 for the role of tournaments).

Our review suggests that some bowfisheries, if properly managed to avoid non-target mortality, can serve both bowfishers and the public interest. Management goals of native species conservation and nonnative species control can be assisted by bowfishing; Fig. 16). Non-native species such as carps, tilapias (*Cichlidae*) and American Shad (*Alosa sapidisima*) offer opportunities. Such fisheries must be managed, however, to avoid developing a formalized constituency (e.g. an "Asian Carp Bowfishers Association") that could develop a vested interest in perpetuating and spreading the same invasive species that public trust managers may be trying to suppress or eliminate. This issue must be clearly understood by bowfishers. In sharp contrast, Montana's trophy-oriented Paddlefish bowfishery in the Dredge Cuts below Fort Peck Dam serves an entirely different goal of providing some unusual (i.e., diverse) sport fishing opportunity for a native trophy fish (Scarnecchia et al. 2008; Fig. 17). Distinct fisheries for disparate species (e.g., invasive nuisance species versus valued native species) obviously require greatly different management regulations. Particularly challenging may be management of species such as gars and Bowfin, ancient native species (Wiley 1976; Robinson and Buchanan 1988; Miller and Robison 2004) which have been shown to have an important, underappreciated ecological function in

Figure 17. Bowfishing for Paddlefish, Yellowstone Sakakawea stock, at Fort Peck Dredge Cuts, Montana. Bag limit is one fish per year. A long-lived species that recruits poorly, Paddlefish may only be suited to limited, tightly controlled, closely monitored trophy fisheries. Careful stock assessment and monitoring for sustainability and maintenance of age and size structure is necessary (Scarnecchia et al. 2014, 2019a). Image courtesy of Zach Kjos, North Dakota Game and Fish Department.

generally aiding, rather than damaging, sport angling (Scarnecchia 1992; Johnson 2015; David et al. 2018). Our tournament survey indicated that gars have remained a popular bowfishing species, both in recorded take and stated preference (Table 3, Fig. 13), perhaps in part because of their sluggish, lurking habits, but also because many anglers and bowfishers still believe, or want to believe, that gar removal is beneficial to other fishes and fisheries (Fig. 18).

Fish life histories and bowfishing management - Effective management regulations for bowfisheries for different species and stocks will need to fully consider important aspects of fish life history, including the natural lifespan, observed patterns of recruitment, and sexual size dimorphism. These topics have received too little consideration from harvest managers in the past, especially for native species not historically valued by anglers or the public. Numerous studies in recent decades have concluded that ages of most commonly bowfished species are greater, often much greater, than formerly believed. Many studies have also shown that these same species often exhibit irregular or episodic recruitment, an evolutionarily acceptable occurrence for long-lived, highly fecund species. For example, Paddlefish is a long-lived species (>60 yr); especially in northern stocks (Scarnecchia et al. 2007; 2019a). Northern Paddlefish stocks recruit much later in life and live about twice as long as fish from southern stocks, associated with their different metabolic demands (Scarnecchia et al. 2007, 2011; 2019a). This characteristic applies to other long-lived bowfished species (e.g., Bowfin: Koch et al. 2009), potentially necessitating different stock specific harvest strategies among states and regions. Paddlefish also typically recruits poorly and episodically (Scarnecchia et al. 2009; 2014; 2019 a,b). The Alligator Gar, another trophy species, is long-lived (25-60 years: Daugherty et al. 2020). Maximum age may be as great as 85-95 years (Mississippi: 149 kg fish, age estimated via otoliths, D. K. Riecke, Mississippi Department of Wildlife, Fisheries and Parks, personal communication). The species also evidently recruits sporadically (Buckmeier et al. 2013; Smith et al. 2020). Recent research has documented extreme old age of Bigmouth Buffalo from northern stocks (>100 years; Lackmann et al. 2019; McFeely 2019; Fig. 19) as well as episodic recruitment. The same characteristics - long lifespan, episodic recruitment, or both, occur in other native bowfished species, including Smallmouth Buffalo (Love et al. 2019), Black Buffalo *Ictiobus niger* (Lackmann et al. 2019) and Blue Sucker (Neosho River, Kansas: Moss et al. 1983; Milk River, Montana: Bednarski and Scarnecchia 2006; Red and Kiamichi rivers, Oklahoma: Dyer 2018), all catostomids

Figure 18. Longnose Gar are a popular target among bowfishers due to their perceived abundance, large size, and low social value as a nongame species with an historically poor reputation (Scarnecchia 1992). Bowfishing tournaments often use trash receptacles to weigh the fish. Although a popular target, all gars provide substantial ecological benefits to waters they inhabit. Their removal from waters should be judicious and accurately monitored for sustainability and maintenance of age structure. Images of 2018 Bass Pro Shops® U.S. Open Bowfishing Championship in Broken Arrow, Oklahoma, courtesy of Kelly Bostian, Tulsa World © 2018.

that have recently been found to live to a much older age that formerly thought, and all of which biologists have long observed typically yield few small, young specimens during most annual sampling (e.g., Blue Sucker, Dyer 2018; Southeastern Blue Sucker, *C. meridionalis:* Pearl and Pascagoula rivers, Mississippi, Peterson et al. 1999), a result consistent with unreliable, episodic recruitment (e.g., Bigmouth Buffalo; Johnson 1963).

Sexual size dimorphism in bowfished species is of critical concern in formulating management of bowfisheries. Whereas in terrestrial and avian species bowhunters most commonly target, such as deer and elk (Cervidae), wild turkeys (*Meleagris gallopavo)*, and even wild or feral swine (Suidae), males reach a much larger size than females (Jarman 1983; Badyaev 2002; Lindenfors et al. 2007; Parés-Casanova 2013), in fish species targeted by bowfishers, the opposite is the case (Bell 1980). Paddlefish are sexually size dimorphic in all documented stocks, especially in northern stocks (Yellowstone-Sakakawea, Fort Peck: Scarnecchia et al. 2007; 2008) where mature females are nearly all larger than mature males. The largest Paddlefish targeted are all, or nearly all, females (Scarnecchia et al. 2007; 2014, 2019;). The Alligator Gar is also sexually size-dimorphic, with the largest, heaviest fish rangewide being females (Alabama: Irwin et al. 2001; Louisiana: DiBenedetto 2009; Texas: Binion et al. 2015; Texas, Arkansas, and Florida: Daugherty et al. 2019, 2020). During spawning, large female spawners may also concentrate in shallow, temporarily flooded areas (Lower Mississippi River: Allen et al. 2020) where their vulnerability to bowfishing may be greatly increased. The tendency for females to reach a larger size than males is indicated from data for Bowfin (Koch et al. 2009), Longnose Gar (Missouri: Netsch and Witt 1962, Johnson and Noltie 1997; Charleston Estuary, South Carolina: Smylie et al. 2016), Spotted Gar (Lake Pontchartrain

Figure 19. The Lackmann et al. (2019) study of extreme old age of Bigmouth Buffalo (>100 years) makes intensive bowfishing of this native species, as well as related taxa, much less sustainable than previously thought and much less scientifically justifiable than bowfishing invasive species. As concluded by Alec Lackmann, fisheries scientist from North Dakota State University, (pictured above, holding an old Bigmouth Buffalo) "They should not be called 'rough fish,' which carries a negative connotation. They should be viewed as an ecological asset … We need to start recognizing Bigmouth Buffalo and other native fish species as the [ecological] assets they are" McFeely 2019, p. 1). Any killing of buffalofishes should always be accompanied by accurate monitoring of the kill and defensible stock assessments. Image courtesy of A. Lackmann, North Dakota State University.

estuary, Louisiana: Love 2004; Lake Thunderbird, Oklahoma: Frenette and Snow 2016), Blue Sucker (Yazoo River, Mississippi: Hand and Jackson 2003), Freshwater Drum *Aplodinotus grunniens* (Alabama: Rypel 2007), Southern Stingray *Dasyatis americana* (Tilley 2011), and nearly all other species likely to be bowfished, although not necessarily to the extreme extent documented for northern stocks of Paddlefish (Scarnecchia et al. 2007; 2008; 2011). The pattern of larger females across taxa has a strong theoretical basis where females mature later in life than males and reach a larger size, with accompanying fitness benefits (fecundity increases) in situations where large fish size in males associated with male dominance in courtship and spawning is not selected for (Bell 1980).

Another related life history factor in setting effective sex-specific bowfishing regulations is the lack of highly obvious sex-specific secondary sexual characteristics in bowfished species (i.e., something analogous to antlers in male elk and deer that are bowhunted) that might have enabled enforceable sex-selective take in the field, at a distance, underwater. Some bowfished species do have visible sex specific differences. All juvenile and adult male Bowfin have a large spot (ocellus) on the upper caudal peduncle which provides deceptive protection (Sanderson-Kilchenstein 2015), most likely from predation; it is much reduced in adult females, i.e., the largest fish of the species). Measurable morphometric differences between sexes are also found (e.g., gars: Love 2002; McDonald et al. 2013), at least with a high, if not infallible, degree of reliability. However,

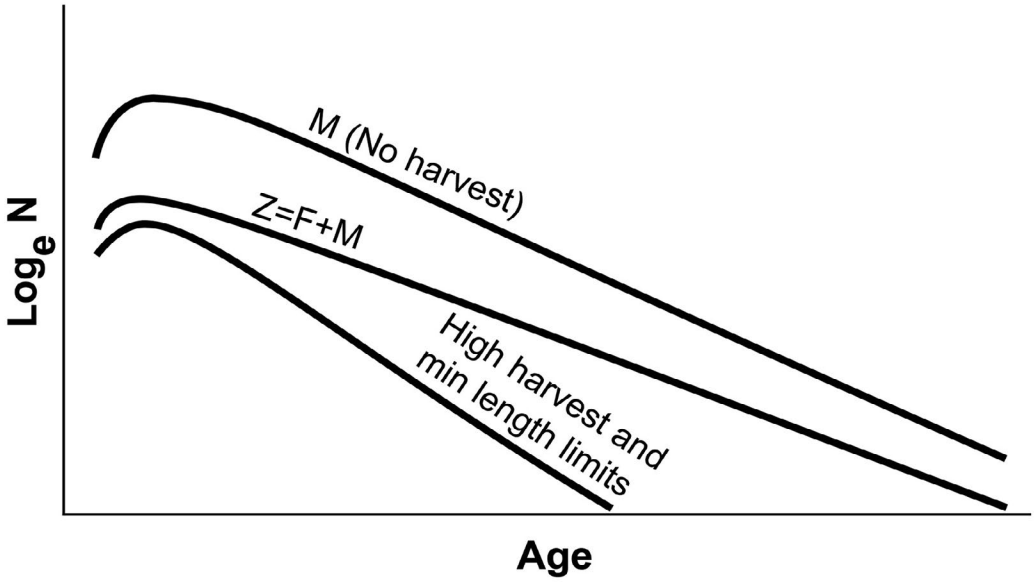


Figure 20. To maintain size, age, and sex structure of a harvested population of a long-lived, sexually size dimorphic fish species (with larger females than males), the harvest strategy should seek to mimic the natural, mortality pattern (top "catch" curve of an unexploited stock) with a lower curve of similar slope (middle curve), avoiding deleterious age and size truncation associated with selective take of only large, old fish (bottom curve). If length or weight is substituted for age on the x axis, removing the longest, heaviest fish in sexually size dimorphic fish species such as gars, buffalofishes, and other bowfished species will also selectively remove females from the stock. M, F, Z = instantaneous rates of natural, fishing, and total mortality, respectively; N = number of fish. Adapted from Scarnecchia (2014; 2019a).

the differences are only useful for managers if live fish can be observed, sorted, and released alive close-up, such as in angling, some types of commercial harvest, or directed sampling for monitoring stocks, where fish are kept alive and in good condition at the time of processing. These opportunities do not exist for bowfishing.

With sexual size dimorphism, managing the sex ratio of the bowfishing kill to avoid excessive harvest of females becomes highly relevant in management for sustainability of the native species. Such selective removal is part of the larger, globally pervasive problem of selective depletion of larger, older fish, (megafauna), in both recreational and commercial fisheries from both freshwater and marine systems (He et al. 2019). Such selective depletion from fisheries has suddenly (on an evolutionary scale) rendered maladaptive their evolved, protracted life history strategies characterized by low natural mortality rates, episodic recruitment, delayed maturation and long lifespan, especially for females (Scarnecchia et al. 2019a). The problem has been identified in fisheries (Francis et al. 2007; Kuparinen and Merilä. 2007; Kolding et al. 2014) but is being effectively dealt with in very few situations (e.g., Paddlefish: Scarnecchia et al. 2014; 2019a). The message for managers of these freshwater bowfisheries is that, just as with Paddlefish, bowfisheries for Alligator Gars, other gars, Bowfins, buffalofishes, and other native species require careful stock assessment and monitoring for sustainability and maintenance of age, size, and sex structure (Kuparinen and Merilä 2007; Scarnecchia et al. 2014, 2019a; Fig. 20). Age and size truncation, as well as selective harvest of females, should be avoided, a goal typically inconsistent with more common regulations

such as minimum size limits. Instead, harvest should mimic the natural mortality of the stock where possible, allowing some old, large fish, most of which will be females, to persist (Francis et al. 2007; Kuparinen and Merilä 2007; Paddlefish: Scarnecchia et al. 2014; 2019a). In managing native fishes and their recruitment, selective removal of females from poorly or marginally recruiting species should particularly be discouraged.

Managers of bowfisheries and other fisheries must also be alert to the probability that populations of gars, Bowfin, buffalofishes, and other species that have been actively exploited may have already undergone age and size truncation (Scarnecchia et al. 2019a) before the time of stock assessment, as the largest, oldest, more-often female fish had previously been killed and removed. As evidence of this problem in gars, for example, Murie et al. (2009) reported on sex-specific age and growth of unexploited Florida Gar (*Lepisosteus platyrhincus*) in two Everglades canal systems and found that females reached age-19 and were much larger than males, which only reached age-10. The dimorphism in this situation (i.e. the presence of larger, older females) was much more extreme than reported in many of the other populations of exploited gar species discussed here. Stein and King (2019; fig. 3.5) reported that bowfishers exploiting Shortnose Gars in Illinois killed larger individuals than were collected with their field sampling gear; a bowfishing take, which, in the absence of some unknown sex specific behavioral differences, would select preferentially for females.

The necessity of managing for age, size, and sex structure presents numerous challenges for managing bowfisheries. For example, some Bowfin and smaller gar species may tolerate controlled, monitored take, although such removal may not be desirable in areas where they are species of concern (e.g., Shortnose Gar in Montana; T. Haddix, Montana Fish, Wildlife and Parks, Personal Communication). Targeting Alligator Gar, a declining species prone to local extirpation (DiBenedetto 2009), may be much more difficult to justify after a careful stock assessment. Bowfishing for trophy Alligator Gar has gained in interest and the need to better understand and manage the fisheries has been increasingly recognized by some managers (Fig. 21; Bennett and Bonds 2012; Bennett et al. 2015; Smith et al. 2020). The same conscientious harvest management needs exist for bowfisheries for buffalofishes (Lackmann et al. 2019), Paddlefish (Scarnecchia et al. 2019a), and other native species. In sharp contrast, in situations where intentional overfishing or extirpation of nuisance species (e.g., Asian carps) is sought, any selective removal of females over males would be beneficial. Bowfisheries on invasive species that have little or no by-catch or other harmful effects to aquatic systems will allow the managers much more flexibility and latitude.

The same message -- the potential for overkill by bowfishing and the need for stock assessments -- is not confined to fishes commonly thought of as freshwater species. Arguments favoring carefully managed kill, maintenance of size, age and sex structure, and accurate stock assessments also apply to bowfishing for low fecundity species such as rays (Camhi et al. 2007; Field et al. 2009; Ogburn et al. 2018). Like gars and Bowfin, rays, both freshwater and marine species, are ancient (De Carvalho et al. 2004), adaptable survivors often disliked and even feared by the public because of their potential to injure (and very rarely kill) swimmers, divers, and occasionally fishers, especially tourists, from venomous spines and secondary infections (Grainger 1980; Diaz 2008). In the many cases where rays (e.g. Cownose Rays *Rhinoptera bonasus*) may congregate in shallow, warmer waters, conflicts with an ever-increasing surf-seeking human population are increasing (e.g. Cole 2019), leading to calls for depletion that bowfishers have sought to answer. For example, "There has been concern about the increasing population size of Cownose Rays due to their predation of oyster beds. The oyster population has

Figure 21. Apex predators such as this 102 kg Alligator Gar that exist in very low numbers relative to Asian carps and often recruit poorly are not promising candidates for sustainable bowfishing, despite their popularity as trophy fish. Any bowfishing take of this species must be tightly controlled and monitored (Bennett et al. 2015). Image from YouTube user Tim Wells Bow Hunter [https://youtube/lQl-JzSENKk].

been decreasing due to diseases and pollution reducing their grass bed habitat. It is thought that Cownose Ray's high predation of oyster beds could further complicate the problem of declining oyster populations. The Virginia Sea Grant Marine Advisory Program has considered solving this problem by proposing commercial fishing of Cownose Rays. Commercial fishing of this species has not yet been established because of many possible problems associated with it. There is currently no market for Cownose Rays even though participants in a taste test liked the Cownose Ray meat." (University of Florida Museum 2020). Even though bowfishing for rays has become popular in recent years, and sometimes seen as a public service by bowfishers, the effects on the ray populations are poorly known. In our survey, only two states (Delaware and Maryland) commented specifically on bowfishing for rays; only Maryland noted concerns for the sport. Like the other species discussed here, rays have, with a few exceptions, been perceived as nuisances and therefore have a history of inattentive or no management (Charvet-Almeida et al. 2002; Dulvy et al. 2017).

What is known, however, is that fecundity of these species, in terms of numbers of offspring, whether viviparous or oviparous (Wourms 1977; Blackburn 1999) is very low. As strongly K-selected species (Adams 1980; King and MacFarlane 2003; Tilley 2011), rays have few young and make a high reproductive investment in them, a life history whose success is predicated on a low total mortality rate of recruited offspring, including from fishing. Cownose Rays, which have become a

popular bowfishing species along the Atlantic Coast and Gulf of Mexico (Fig. 22), were found by Neer and Thompson (2005) to have a gestation period of 11-12 months. Gravid females contained only one pup. Low brood size has also been commonly found in the Southern Stingray (Henningsen et al. 2000; Tilley 2011) and other rays.

Despite these life history limitations, rays commonly present the illusion of being highly abundant and, ergo, of recruiting robustly because of their tendency to move in groups, often in search of the warmer temperatures of shallow nearshore waters and lagoons frequented by swimmers and other recreationalists. For evolutionary reasons, the nearshore clustering behavior may also be most commonly practiced by female rays. In explaining an observed 3 female:1 male sex ratio of the Southern Stingray in shallow waters, Tilley (2011) reported that higher lagoon temperatures are most likely accounted for the skewed sex ratio, where females actively selected warmer temperature. Wallman and Bennett (2006) found that increased temperatures of even 1°C decreased gestation periods of up to two weeks. Their perceived high abundance is more related to their behavior (visibility), lack of perceived value as food amid more robustly-recruiting but desirable food and game species, and habitat alterations favoring their localized dominance over other species (e.g., Parana River: Brazil and Paraguay; dos Santos et al. 2019). Because they are not typically favored as food, wanton waste of rays has also been identified (Lahn 2018). With their strong K-selected life histories and miniscule number of ova produced compared to all other bowfished taxa heretofore considered, they are not capable of even providing the occasional boom year classes of episodic recruitment that can sometimes lead to rapid expansion or recovery of some other bowfished taxa (Scarnecchia et al. 2011; 2019). Although rays outside of petting zoos in public aquaria are not currently stylish species with the public, for longer-term ecological reasons their removal should always be justified through scientifically defensible stock assessments. For some species such as the Cownose Rays as well as even rarer ray species, it is possible that because of their low fecundity, they may be demographically completely unsuited to bowfishing, despite their current popularity with enthusiasts (Fig. 22).

Figure 22. The Cownose Ray has become an increasingly popular bowfishing species, often perceived to be abundant and a nuisance to the public and to oyster beds, even though a study by Neer and Thompson (2005) found that females of the species have a gestation period of 11-12 months and carry only one pup. Image Source: [www.bowfishingassociation.com]

The effects of culling - In addition to monitoring the freshwater and marine fishes killed and kept for weigh-ins, culling needs to be more carefully assessed and monitored in bowfisheries. As the case study of the U.S. Open tournament demonstrated, the big 20 tournament format resulted in the killing and waste of an

Figure 23. Buffalofishes, native suckers (Catostomidae), long known as important commercial species (Coker 1930; Ross 2001), have become popular bowfishing targets and have often unjustifiably been viewed as "rough fish" and incorrectly grouped with invasive species as unworthy of monitored kill and careful stock assessments. In this case, as in many others, bowfishers often take these fish indiscriminately with Common Carp, as depicted here. Images courtesy of Zach Kjos, North Dakota Game and Fish Department.

estimated additional 1,919 fish (41% of the tournament take). These fish were not taken to the weigh-in where they could be enumerated by species; tournament data on take must be collected in such a way to examine the true kill totals. Whereas bowfisheries may create few or no problems in cases of common, recruitment-rich invasive species, they can become a major source of mortality for long-lived species, native species of concern, or those with low reproductive success or episodic recruitment, such as Bigmouth Buffalo (Lackmann et al. 2019), Paddlefish (Scarnecchia et al. 2019b), and Alligator Gar (Buckmeier et al. 2013; Daugherty et al 2019, 2020).

Similarities of appearance - Similarities of appearance can present another problem for the manager of bowfisheries. Bowfishers correctly identifying their quarry at an angle in often turbulent, turbid water must do so under a complex array of differential color-specific light penetration, refraction, and distortion (Hutchinson 1975). In addition, ODWC interaction with bowfishers at the U.S. Open tournament provided evidence that considerable confusion in species identification can occur among and within families of fish, even when the fish are viewed close-up, under ideal conditions, above water by tournament bowfishers, whose passion for the sport might lead them to be more knowledgeable than the average independent bowfisher. Other studies on anglers elsewhere in bowfishing regions support these findings (Nebraska: Reed 2011; Ohio: Page et al. 2012). Invasive species such as Asian carps and Common Carp may be targeted, yet native, long-lived species that recruit more poorly and more episodically than the invasives may be inadvertently, and pointlessly, killed or maimed (Table 3). Consequences can be substantial. Among cypriniform species, for example, buffalofishes, long recognized as important commercial fishes (Coker 1930; Ross 2001), were reported as a popular bowfishing species (Fig. 23) and can often be difficult to distinguish in the water from carps. Similarly, bowfishing for invasives such as

Northern Snakehead *Channa argus* may lead to unintentional excessive killing of Bowfin, which can be difficult to distinguish from snakeheads, especially under water at a distance (Kusek 2007). Overall, the ancient Bowfin (Patterson and Longbottom 1989; Grande and Bemis 1998) remains a much maligned (Scarnechia 1992), poorly understood, (Koch et al. 2009; Midwood et al. 2018), minimally managed species that nevertheless has long been a source of caviar (Scarnecchia 1992; Sanderson-Kilchenstein 2015; Polumbo 2016). A recent study by Polumbo (2016) of morphometric variations among Bowfin suggested that there may be more than just one extant species, leading to additional management concerns and a greater likelihood of species or distinct stock overharvest and extirpations associated with species misidentifications. A similar conclusion can be reached for the threat to distinct stocks or subspecies of the Blue Sucker and Southeastern Blue Suckers (Peterson et al. 1999). Suckers in general remain poorly studied (Cooke et al. 2005) ecologically and taxonomically; overharvest of distinct but unidentified stocks cannot be ruled out. Freshwater Drum can also be inadvertently killed by being mistaken for an invasive carp. Some ray species are also difficult to distinguish in nearshore waters.

Other management challenges - The mobile format in some tournaments and many non-tournament expeditions by private groups where bowfishers can move quickly among numerous waters statewide, can create additional management concerns. In contrast to angling tournaments (e.g. Largemouth Bass), which are typically held on a single water body, bowfishing tournaments utilizing multiple water bodies present a notably increased risk of spreading aquatic nuisance species. Problems in species identification can be exacerbated where their knowledge of site-specific species composition is poor. Unintended by-catch will vary as species composition varies among waters. To managers attempting to contain the spread of ANS, their greatest concern might be that rapid movements of bowfishers also greatly increases the opportunity for transfer of invasive flora and fauna such as Eurasian water milfoil *Myriophyllum spicatum,* zebra mussels *Dreissena polymorpha* (Rothlisberger et al. 2010), or fish.

Bowfishing can also create challenges in safety and compliance for enforcement branches of agencies. Although Palsbo (2012) found that archery per se is a very safe sport -- far safer than hunting with a gun, the more dangerous bowfishing activities may involve boating (the number one single cause of deaths: U.S. Coast Guard 2019; McKnight et al. 2007), associated boat-trailering, and driving to and from bowfishing sites. Over concerns for safety and liability, most of the high profile modern bowfishing tournaments have been proactive in prohibiting drug or alcohol use during events (Cajun 8 2020), and often prohibit use immediately before and after the events as well (AMS Bowfishing 2020; West Bend 2020). States often also have specific statutory wording against hunting with a bow and arrow under the influence of alcohol or drugs. Unstructured, unmonitored, bowfishing may present a different picture from organized tournaments, however. Bowfishing, like other sporting activities, has long been associated with concurrent alcohol usage (Gutgesell and Canterbury 1999; Vamplew 2007). Reilly and Halliday (1985) documented how, as of 1985, the Grand National Archery Society of Great Britain had not yet banned alcohol use in its competitions "in small doses in the belief that it relaxes the competitor and so steadies the hand" (p. 100). However, their research failed to support the long-held belief that alcohol use enhanced archery performance (Reilly and Halliday 1985). Alcohol use nevertheless has many complex relationships with hunting and fishing that transcend performance (Vamplew 2007). The main effects in unmonitored bowfishing may be on the fish kill. Potential effects may include enhanced aggression and wanton disregard by the bowfishers toward quarry (Bushman and Cooper 1990; Bartholow et al. 2005; Wilson and Peden 2015) and increased likelihood of visual species misidentification well-documented in

Figure 24. Bowfishing tournaments can provide a centralized, cost-effective venue for kill data collection (e.g., King et al. 2018) by state fish and wildlife agency personnel, as conducted here by ODWC at the 2018 Bass Pro Shops® U.S. Open Bowfishing Championship in Broken Arrow, Oklahoma. Success requires cooperation from tournament promoters, support from tournament sanctioning bodies, or a tournament permit system with mandated kill reporting. Image courtesy of Kelly Bostian, Tulsa World © 2018.

anglers (Reed 2011; Page et al. 2012) and the broader public, under poor viewing conditions and with alcohol use (Woocher 1977). In particular, it is not well documented how alcohol or drugs may affect bowfisher behavior toward unpopular, so-called "trash fish" such as gars widely regarded by them and the public as nuisances. More studies are needed on the often simple, but sometimes complex, psychological aspects and motivations of regulation violations and wanton waste (Muth and Bowe 1998; Eliason 2003; illegal or reckless fishing as fun: Curcione 1992), in this case with reference to bowfishing in particular.

Fisheries monitoring - Efficient data collection must be an integral part of the management of bowfisheries. Based on past studies (e.g., Quinn 2010) and ODWC's experience at the 2018 U.S. Open, large and small bowfishing tournaments may provide a cost-effective venue for immediate and thorough data collection on species composition of bowfishing take (both preference and practice), demographics of bowfishers, and other topics relevant to fisheries managers (such as the potential transmission of ANS). Tournament surveys, either through cooperation or by mandate (via a tournament permitting system with required take and participant reporting), may provide the data currently lacking for adequate and proactive management by state agencies (Fig. 24). Non-tournament creel data will also be useful. Much data will come from killed fish. However, non-lethal sampling of fish by agencies (apart from tournament sampling) is also an option

that can yield complementary sex-specific fish stock data. Research in the past two decades has shown that many of the bowfished species also show sexual dimorphism in ways other than size (morphology: Spotted Gar: Love 2002; Longnose Gar; McGrath and Hilton 2012; Alligator Gar: McDonald et al. 2013; spotting: Bowfin: Sanderson-Kilchenstein 2015) and can be aged with non-lethal methods (e.g., fins: Glass et al. 2011; King et al. 2018), facilitating sex-specific stock assessment and monitoring where needed without the necessity of killing the fish.

Funding the management of bowfisheries - Funding for managing bowfisheries is another issue deserving a new appraisal as the sport expands. Kallman (1987) described how, in 1972, archers and bowhunters joined firearms hunters as active participants in the well-established Federal Aid in Wildlife Restoration Program (Pittman-Robertson Act), enacted in 1937 as a Federal excise tax on hunting equipment. The process of adding archery to the program began in 1970 in a congressional bill sponsored by George A. Goodling (1896-1982), a United States Congressman (R) from Pennsylvania with a history of involvement in Fish and Wildlife Commission activities in his home state earlier in his career. By 1970, Goodling had become the ranking minority member of the U. S. House of Representatives Subcommittee on Fish and Wildlife Conservation, chaired by John Dingell, Congressman (D) from Michigan, for whom the Federal Aid in Sport Fish Restoration Program, a comparable program for fisheries, is named (i.e., Dingell-Johnson Act). In 1972, with the support and influence of Fred Bear, the archery bill finally passed the House and a similar bill passed the Senate and was signed into law by President Nixon. An outcome of archery joining the Federal Aid Program for Wildlife is that a wide array of archery equipment, including bows and bow parts (e.g., sights, grips, wrist slings, bowstrings, and many other accouterments) became taxed at 10-11% with the funds overseen by the Fish and Wildlife Service and disbursed back to the states, who match it with license funds and use the combined sum for wildlife management, restoration, enhancement, and public information and education (U. S. Fish and Wildlife Service 2018; Scott Undated). All taxes collected and disbursed under the Federal Aid programs are for wildlife rather than fisheries except for "reels and spools employed for dispensing and retrieving line attached to arrows….used in fishing (p. 5)" (U. S. Fish and Wildlife Service 2018). Bowfishing opportunities with no bag limits for several invasive species are expanding rapidly. Administratively, many fish and wildlife agencies have separate fish and wildlife divisions. To ensure that the funds are optimally disbursed between the two divisions, and between terrestrial and aquatic spheres, it may become important for managers to gauge participants and effort in the two spheres and allocate funds accordingly.

The need for management - All of these potential stock assessment, management, enforcement, and funding issues call for well-thought out, clearly articulated planning efforts by agencies. Planning needs to consider how to manage the fish and the fisheries, including how to develop and enforce necessary regulations (Eliason 2003) such as time-area closures, possible spawning season protections, and species bag limits, how to manage and monitor tournament activities, and how to best develop and deliver information and education programs.

As a starting point, it may be useful for the agencies to work together through their national networks such as the Association of Fish and Wildlife Agencies (AFWA) and its regional western, midwestern, and southern regional partners (WAFWA, MAFWA, and SEAFWA) to develop, with input from bowfishers and their sanctioning bodies, a proactive framework plan for guiding development of bowfisheries. A framework is necessary to reconcile the distinctly different goals and objectives of the modern sport. States can then work individually and cooperatively as needed in implementing consistent regulations where feasible yet be

responsive to local or regional interests and opportunities. Here we list 10 of the many issues that can be addressed among the states: 1. a discussion of the need to establish bowfishing-specific licenses or permits, as well as tournament permits. License and permit fees might be used to let managers know when and where tournaments are being held (S. J. Rider, Alabama Division of Wildlife and Freshwater Fisheries, personal communication), and used toward conservation and sustainability efforts, enforcement, and creel and tournament data acquisition needed for management (Fig. 24); 2. how to cost-effectively manage and monitor the fisheries, amid increasing participation and technology-driven fishing power, with its potential effects on native species; 3. how to evaluate and manage these fisheries with necessary regard to age, size, and sex specific data needed on the stocks (Fig. 20); 4. the lack of productive use of the vast majority of fish, especially native fishes, killed by bowfishing and when wanton waste constitutes a problem (Figs. 18, 23); 5. the increase in night bowfishing and its potential challenges and consequences for effective management and enforcement (Cooke et al. 2017); 6. a commitment to research non-harvest mortality and consideration of regulatory options to reduce the likelihood of escape of maimed fish (e.g. mandating dip nets); 7. how to work with enforcement branches of agencies, bowfishers, and the industry in developing regulations amenable to scientifically and socially defensible, cost-effective, enforcement (Rider et al. 2019). It is important to develop meaningful conservation regulations while gaining the support of an already established, and entrenched, industry that has developed around bowfishing, so that the sport and its advocates serve the broader long-term public interest rather than short-term economic benefits of a few people (Rider et. al. 2019); 8. how to obtain minimally biased, relevant information on bowfishers and the general public and their interests and motivations surrounding bowfishing. Comparative information is needed between perspectives of bowfishers and the general public, who may have different values regarding bowfishing; 9. the need to implement education programs to change the long-standing, intergenerational biases against misunderstood native species (Spitzer 2010) that generations of fisheries professionals have not yet succeeded in accomplishing (Weed 1923; Scarnecchia 1992; Lackmann et al. 2019). This need includes proactive information and education for the many new bowfishers entering the sport; and 10. how to fund these management efforts in the context of existing programs (e.g., Federal Aid via the Wildlife and Sport Fish Restoration Program) and new programs where necessary. Effective management of bowfisheries and the native species taken will require more attention and finesse than formerly recognized, and considerably more funding than has been available in the past. Funding limitations will require managers to be creative in determining how fisheries are permitted and designed to achieve the needed goals and objectives (Rider et al. 2019), especially those involving valuable, even if widely underappreciated, native species.

Henry Wadsworth Longfellow's poem "The Arrow and the Song" begins "I shot an arrow into the air, It fell to earth, I knew not where." As managers of the Public Trust, the challenges for state and federal management agencies are to use well-conceived planning and modern technology, cooperate with other agencies, and work with bowfishers, archery and bowfishing organizations, and the public in managing bowfisheries, as other fisheries, as instruments of aquatic species conservation, public benefit, and sound long-term public policy. To prevent Longfellow's classic poem from devolving into doggerel in the realm of management of bowfisheries, managers need to know the bowfishers, work with them, but proactively and judiciously manage their arrows as they fall: how many, where, when, and on which species.

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